December 1982 A.E. Res. 82-45

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Susan E. Offutt

Department of Agricultural Economics
Cornell University Agricultural Experiment Station
New York State College of Agriculture and Life Sciences
A Statutory College of the State University
Cornell University, Ithaca, New York, 14853

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THE IMPACT OF EXPORT INSTABILITY ON THE US CORN AND LIVESTOCK MARKETS: AN ECONOMETRIC ANALYSIS

by Susan E. Offutt*

* The author is Assistant Professor, Department of Agricultural Economics, University of Illinois.
This bulletin is based on the author's Ph.D. dissertation and was prepared while she was a graduate student at Cornell.

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INTRODUCTION

Corn, the major feedgrain grown in the United States, is the primary input to the domestic livestock sector. Almost a third of the annual crop is exported, most to the high-income countries in Western Europe and to Japan, for use in their livestock economies. The centrally-planned nations, particularly the Soviet Union, have been importing increasing amounts of corn as an input to livestock production in their efforts to upgrade consumer diets. The significance of livestock products in the American food budget and the sensitivity of livestock production and prices to corn prices ensures that conditions in the corn market are translated into measurable effects on consumer expenditures. Furthermore, corn sales abroad generate needed earnings of foreign exchange which offset US purchases of petroleum and other goods, thereby reducing the deficit in the current account of the balance of payments.

Consequently, disruptions in the corn market can materially affect American economic interests. Dislocations in the form of instability in prices are often the hallmark of agricultural commodity markets. Relatively small changes in production, coupled with an inelastic demand schedule, result in disproportionate price movements. Domestic US demand for corn does tend to be rather price inelastic, and production is always susceptible to the stochastic influence of weather. Because such a large portion of each year's crop is sold overseas, there exists another potential source of instability. Unpredictable shifts in other countries' demands, as exemplified by the behavior of the Soviet Union over the past decade, act to shift the aggregate demand curve, thus affecting domestic US prices in an unforseeable fashion. Consequently, short-run inelasticity of domestic demand coupled with volatile export demand compound the problem of corn price instability.

While the decade of the 1970s may have witnessed an extraordinary number of disruptions (the OPEC oil embargo, several extremely poor harvests, and such), it seems unreasonable to expect, over the next ten years, a return to the comparative calm of the 1960s. Domestic demand for corn will not slacken, even if it does not increase as rapidly as in the past. Internationally, the US has become a residual supplier to a residual market. That is, of a handful of exporters, the US supplies over 75 percent of corn traded and adjusts its export supply, at the expense of the unprotected domestic market, when the demands of the foreign nations change. Fluctuation in these overseas demands is likely when importers seek to balance their own domestic requirements (influenced by stochastic production) with supplements from the world market, often with little concern for cost. A corn market in the 1980s with this configuration holds the potential for the kind of instability experienced in the past.

The purpose of this bulletin is to evaluate the effects of instability in Soviet corn imports on the US domestic corn/livestock and export corn markets. A structural econometric model is specified which portrays the process by which the various market sectors adjust to shocks. Identification of the nature of the transmission of instability then provides information which may be used to formulate policy to control or ameliorate its effects.

An equilibrium supply-demand model is used to describe the structure of the corn market. The econometric model explains the consumption of US corn domestically and on the export market, as well as US corn production and price. The production and consumption of US livestock products (fed beef, nonfed beef, pork, poultry) are explained, as are these products' prices. The livestock and corn markets are linked through derived feed demand relationships, so cyclical movement in the former is transmitted to the latter. The model is annual in period, except for the hog production sector which is semi-annual, and is estimated over 1961/62 to 1978/79. The corn crop year, from October 1 to September 30, defines the annual period.

In the structural model, the various livestock sectors are disaggregated. Beef cattle, hog, and broiler production are described in a series of recursive equations. Current livestock product prices are determined by demand at the wholesale level. The demand for feed corn is derived from current livestock production levels. The demand for corn on the world market is composed of a set of demand estimates for groups of importers, aggregated according to their similar importing characteristics. The US is set as the residual supplier to the world market; corn exports by other countries are exogenous. Equilibrium corn price is determined endogenously when the world market clears.

The current interest is to use the structural model to analyze market adjustment to erratic corn imports by the Soviet Union. To accomplish this, the deterministic paths of the exogenous variables are projected over the period 1980/81 to 1989/90 and the model solved with Soviet corn import behavior as the only source of stochastic fluctuation. Using Monte Carlo techniques, mean paths for key variables over the next decade are found, which reflect behavior under stable market conditions. The impact of volatile Soviet behavior over this period can be isolated by examining individual stochastic simulation runs.

This bulletin presents a structural description, empirical model, and stochastic simulation analysis of the US corn/livestock and corn export markets. As preparation for the introduction of the empirical model, the next section examines the characteristics of the market's components. The specification, estimation and validation of the structural econometric model are described in the following section. Finally, the model is used to examine the possible market impact of continued volatile Soviet corn import behavior in the 1980s.

MARKET DESCRIPTION

The market for United States corn has domestic and foreign components, both of which arise primarily from the demand for the feedgrain as an input to the livestock sector. In addition, corn for food, seed and industrial use as well as for private and government stocks is demanded by US domestic market participants.

Consumption of US corn by domestic livestock and poultry has accounted, on the average over the past five years, for about 61 percent of total corn disappearance, or about 100 MMT (4 billion bushels) annually. Figure 1 shows the general upward trend of corn consumption by the livestock and poultry sectors over the past 20 years. On the same graph is total domestic corn disappearance which displays behavior almost identical to that of the feed series. The constant margin between the two reflects the historical constancy of the other components of domestic disappearance.

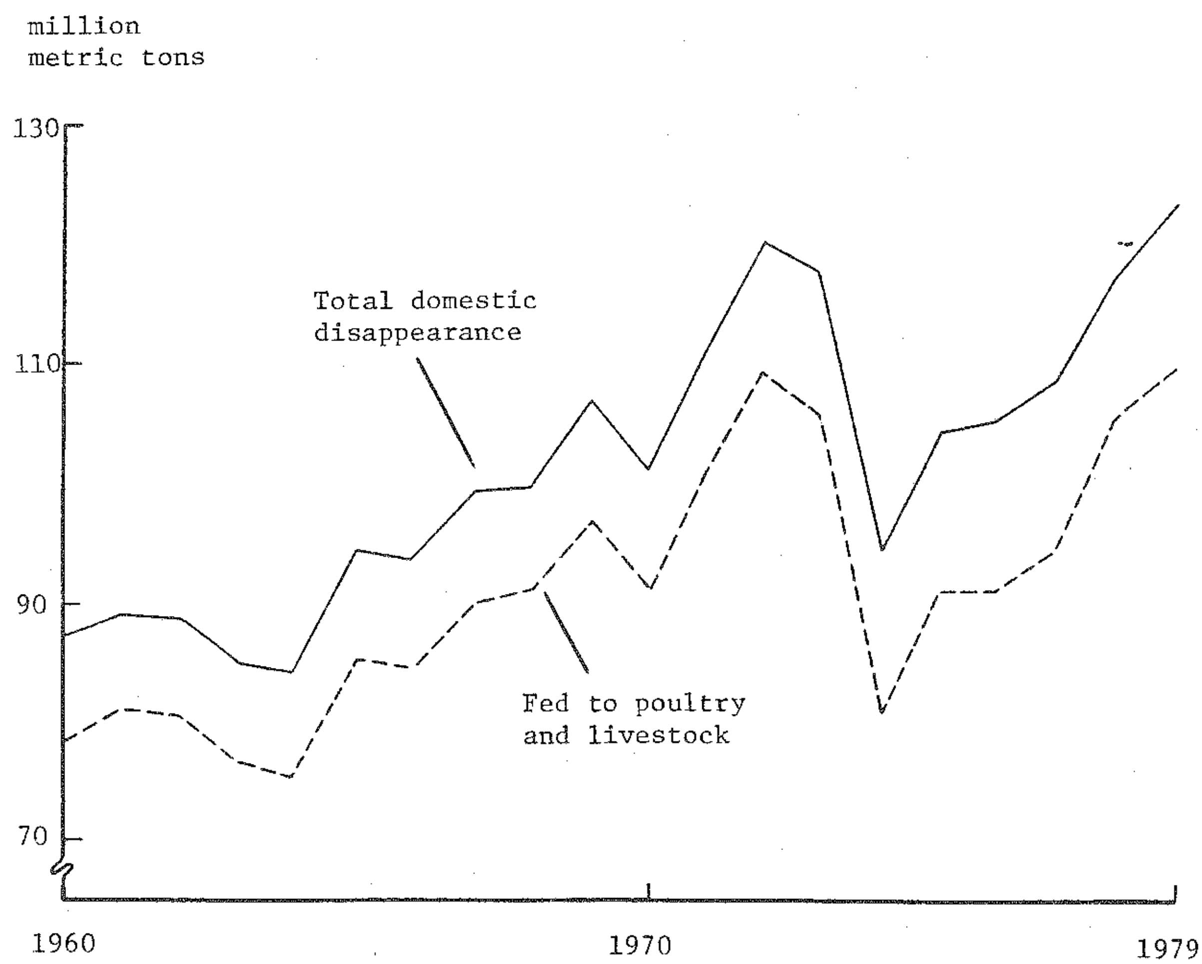
Four broad livestock categories have historically accounted for more than 95 percent of feed corn consumption, although the shares of these categories have changed over time. These livestock groups are milk cows and other dairy cattle, cattle on feed and other beef, hogs and poultry (which includes laying hens, pullets raised for layer replacement, broilers and turkeys). Figure 2 traces the relative shares of corn fed by livestock category over the period 1960 to 1980. Poultry and dairy uses exhibit smooth, gentle upward slopes, while hog and beef cattle shares display a more variable and inverse relation to each other.

The poultry category includes in the aggregate all layer and broiler chickens and turkeys. Almost all the increase in corn consumption by poultry is attributable to an increase in the amount fed to broilers, moving up from 5.22 percent of total corn fed to livestock in 1960, to 6.38 percent in 1970, and to 8.77 percent in 1980. Meanwhile, consumption by layers was fairly steady at about nine percent and turkeys at two percent. These consumption statistics do not reveal increases in feeding efficiency over the past twenty years. Broiler production has increased over 600 percent in that time to about 4 billion birds in 1979 (USDA 1980a, p. 480), but corn consumption has not increased commensurately. At the same time, there was a small decline in the layer population and turkey numbers increased slightly.

The dairy cattle category is comprised of milk cows and other dairy cattle (e.g., bulls, all together have accounted for about 10 percent of the total dairy cattle population over the past twenty years). While the dairy percentage of total corn fed has remained relatively constant over the period, the number of dairy cows has declined. Each cow today produces "two and one-half times as much milk as her foremothers only 30 years ago" (Crittendon, p. F6). While future changes in feeding regimens and corn/milk conversion efficiency are hard to predict, it does not seem reasonable to expect major impacts on the corn market, especially since the dairy sector accounts for only about 16 percent of all corn fed to livestock.

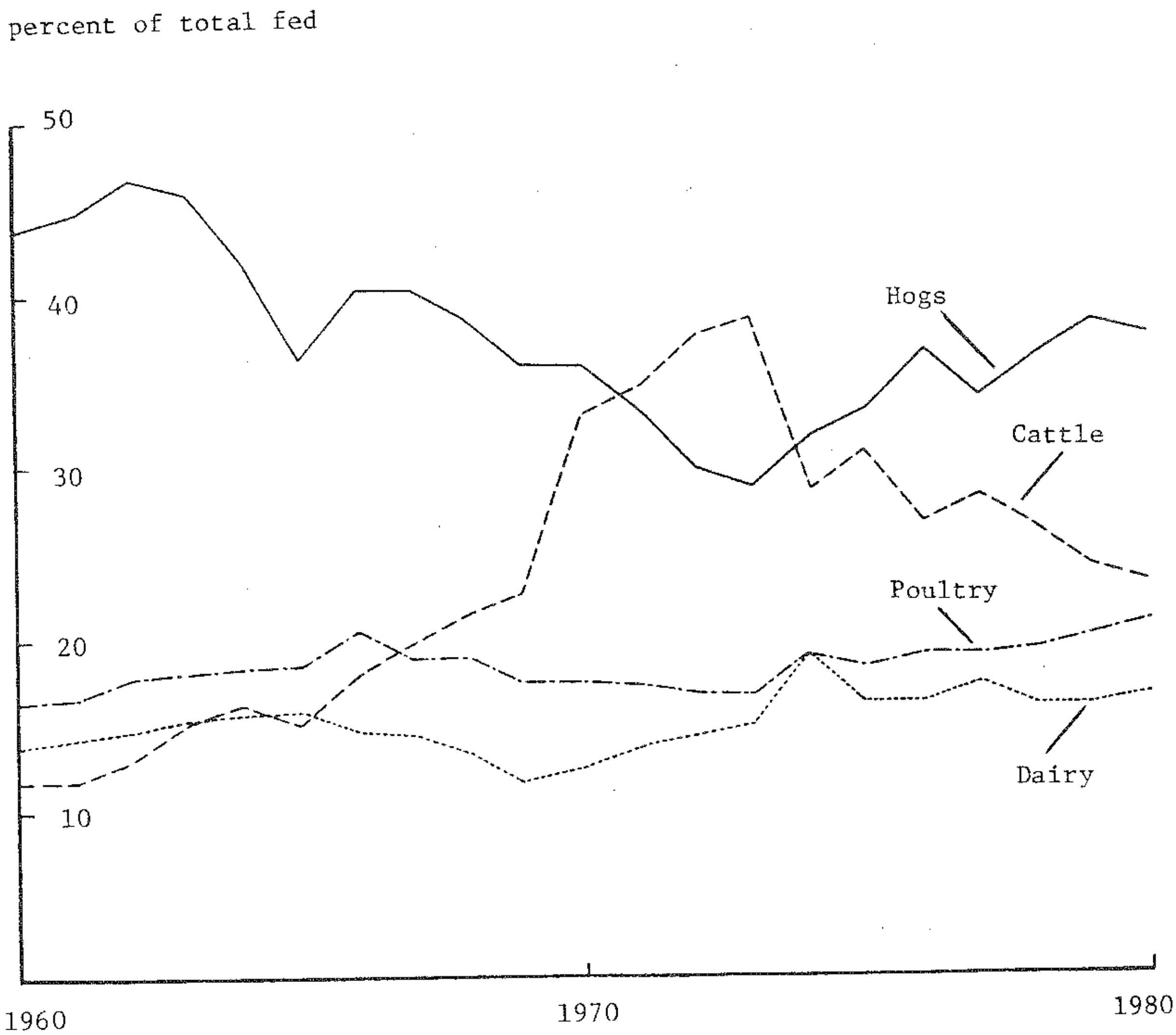
In all but three of the past twenty years, hogs consumed a larger percentage of total corn fed than any other type of livestock. For the three years when the hog share declined below that of beef cattle, the reversal is attributable to an increase in beef cattle production rather than a marked decline in hog numbers.

Figure 1 US domestic corn disappearance 1960-1979



Source: USDA OASIS Data Base

Figure 2 US corn fed to livestock, by category 1960-1980



Source: USDA ERS

These corn consumption levels reflect livestock production patterns from which their demand is derived. In this respect, two characteristics of the domestic US livestock sector are salient, the short-run elasticity of supply and the longer-run production cycles, particularly in the beef and hog subsectors. In the short run, within a year or six months, livestock numbers are fixed and output can be increased only by feeding animals to heavier weights or by slaughtering members of the breeding herd; consequently, response to current own or input price is not great (although flexibility varies among sectors). In the longer run, expansion of future output can be achieved by adding to the breeding herd. The breeding to market phase for hogs takes about two years, while for cattle the elapsed time may be three to four years. Derived corn demand in the short run, then, will depend upon production flexibility in feeding, as well as the number of animals available for slaughter. In the longer run, feed demand for corn will be determined by overall production levels, which were influenced by prices expected several periods earlier.

Cyclical phases in hog and cattle numbers arise due to a rather complex interaction between economic forces and biological constraints. These cycles run eight to ten years from peak to peak in the beef cattle sector and about three to four years for hogs. The absolute level of peak production has changed from cycle to cycle, although relative intracycle relationships have been more or less constant. Consequently, derived corn demand is influenced by the magnitude and timing of the buildup and liquidation in any given cycle.

The price responses implied by these production characteristics are made within the context of specialized livestock enterprises. As long as grain supplies and prices were stable, large-scale operations were further encouraged. However, fluctuation in either input or output prices, as occurred in the 1970s, poses problems for producers. Gustafson explains,

> (This) volatility in grain prices makes formulation of long run plans extremely difficult for the livestock sector. Producers find themselves in a position in which they have little protection against sudden falls in the prices of their livestock and sharply increasing grain prices, particularly during periods of large livestock inventories. (p. 128)

Consequently, livestock producers in the face of price uncertainty may restrict supplies to limit their risk in times of pronounced instability.

Overall livestock numbers have shown a secular increase since World War II. Each peak of the cattle cycle has brought new production and per capita consumption records. Broiler production has increased tremendously, although pork not as much. Table 1 provides per capita consumption data for beef, pork, poultry and dairy products. Beef consumption increased steadily through the 1960s, peaked in the mid 1970s, and fell in 1979 to its lowest level in 12 years. Pork consumption has averaged about 60 pounds per capita annually since 1960. The six-fold multiplication of the broiler population is reflected in the doubling of per capita consumption of poultry meat.

Table 1 US per capita consumption of livestock products (in pounds)

	Beef a/	Pork a/	All Dairy b/	All Poultry a/
1960	64.3	60.3	384	34.4
	65.8	57.6	377	37.7
	66.2	59.1	376	37.2
	69.9	61.1	374	38.0
	73.9	60.9	374	39.9
1965	73.6	54.7	373	41.1
	77.1	54.3	371	43.8
	78.8	59.8	362	45.3
	81.2	61.4	364	45.0
	82.0	60.6	360	47.0
1970	84.1	62.0	355	48.9
	83.6	68.2	355	49.1
	85.9	62.9	357	51.3
	81.1	57.6	352	49.6
	86.4	62.2	346	50.4
1975	88.9	51.2	349	49.6
	95.7	54.6	352	52.9
	93.2	56.7	349	54.5
	88.8	56.5	346	57.2
1979	79.6	64.6	342	62.0

a/ retail cut equivalent

b/ total retail product weight

Source: USDA, 1981b, pp. 4,6,7.

Consumption of dairy products has decreased slightly over the period, a pattern consistent with the decline in milk cow numbers and attendant increase in their productive efficiency.

The proportion of total domestic US corn disappearance represented by seed and food consumption has remained constant over the years since 1960 (see Figure 1). Seed use has usually accounted for less than one half of one percent of domestic disappearance and food use for about ten percent. Food uses include breakfast foods, cornmeal and grits, and wet process products, this last category responsible for about two thirds of annual food corn consumption. Wet process (milling) products include corn starch, corn syrup, crude corn oil and steepwater concentrates (from which such medical supplies as intravenous glucose solutions are made) (Chicago Board of Trade, p. 120).

Demand for corn to be fermented and distilled into ethyl alcohol (ethanol) had traditionally arisen from whiskey producers in Pennsylvania, Maryland, and Kentucky, where lime deposits are sufficiently rich to supply the desired water qualities. However, a new demand for corn has arisen derived from the production of liquid fuel in the form of ethanol. Ethanol's greatest potential as a supplement to national energy supplies is as an octane enhancer when mixed with unleaded gasoline as gasohol. Without the original federal subsidies, the viability of the US ethanol industry depends on the relative prices of corn and petroleum. To date, production has not reached even the one billion gallon mark (using about 10 MMT of corn) originally targeted by Jimmy Carter in 1980.

Over the past decade, an increasingly large amount of corn has been traded internationally. Total trade was 30 MMT during the 1970/71 crop year, had increased to 69 MMT in 1978/79, and was 80 MMT in 1979/80 (USDA 1980b, p. 13). Major corn producers are listed in Table 2, which can be compared to Table 3, which gives the major world corn importers and exporters. Several major producers, notably Eastern Europe, the People's Republic of China (PRC), and Brazil consume practically all their corn output domestically. On the other hand, South Africa and Argentina export significant amounts of their domestic corn production, averaging 35 and 55 percent, respectively. The US annually exports about a third of its corn crop, which has usually accounted for about 75 percent of all corn traded internationally.

Those factors which influence a nation's demand for corn imports can be used to aggregate countries into import blocks. These blocks are formed based on similarities in importing behavior which can be attributed to characteristics of a nation's income level and growth rate, its livestock feeding regimen and its trade policies. First, as per capita income grows, the composition of foods demanded changes. Foodgrains, which usually display low or even negative income elasticity, diminish in importance, while items like livestock products (which use feedgrains as an input), with high, positive income elasticities, become an increasingly large part of food expenditures. Second, the type of grains which can be grown domestically influences their utilization in providing energy to livestock. Consequently, import demand for corn depends not only on livestock numbers and on domestic corn production but also on the production of any other important substitute grains (such as wheat

Table 2 Major world corn producers (MMT)

Country/Region	1978/79	1979/80	1980/81
United States	184.6	201.7	168.9
PRC	55.9	60.9	57.0
Eastern Europe	27.7	34.3	30.1
Brazil	16.3	20.2	21.6
European Community	16.3	17.4	16.6
Mexico	10.2	9.2	10.2
Argentina	9.0	6.4	12.3
South Africa	8.2	10.6	11.0
Soviet Union	9.0	8.4	9.7
Canada	4.0	5.0	5.5
Thailand	3.0	3.3	3.2
All others	46.7	44.9	47.7
World	390.9	421.5	393.8

Source: USDA OASIS Data Base

Table 3 Major world corn importers and exporters (MMT)

Country/Region	1978/79	1979/80	1980/81
<u>Importers</u>			
European Community	17.2	15.8	15.7
Japan	10.9	11.9	13.9
Soviet Union	9.6	14.5	11.4
Eastern Europe	5.5	6.8	8.1
Spain	4.3	4.4	4.5
Mexico	0.6	3.9	4.8
Taiwan	2.6	2.4	2.6
South Korea	2.9	2.3	2.7
All others	15.4	16.6	18.1
World	69.0	78.6	81.8
<u>Expoters</u>			
United States	54.2	61.8	64.8
Argentina	6.0	3.5	8.9
South Africa	2.3	3.7	3.7
Thailand	2.1	2.2	2.1
All others	6.4	7.3	6.4
World	71.0	78.5	85.9

<u>Source</u>: USDA OASIS Data Base

and barley). Third, a nation's agricultural trade policies, which are most often linked to domestic economic and political circumstances, can act to insulate the home market from events in the world market.

Nations which import significant amounts of corn can be aggregated into four groups, based on a consideration of the historical path of their imports and the structural determinants of that path, as discussed above. Table 4 displays the groupings along with their 1979/80 import levels, both in absolute amount and as a relative share of world imports. Together, all groups account for 84 percent of all imports of corn, a percentage which is relatively constant over the past two decades, although the relative importance of the various groups has changed, as shown in Figure 3.

Group I consists mainly of middle income countries. Japan and Israel are the most affluent of the group; Mexico, Malaysia, South Korea, Taiwan and Egypt are included because their increasing affluence implies a strong derived demand for corn through meat consumption. As for domestic production, only Mexico and Egypt grow feedgrains in significant quantities. In terms of trade policy, Taiwan, South Korea, and Mexico have internal support programs for corn production, which usually require the existence of import controls. State trading agencies in South Korea and Mexico administer corn trade in response to planning goals. However, to the extent that these goals reflect increased consumption of livestock products in an improved diet, imports may not be unduly stifled. The remaining Group I countries do not interfere with corn trade although Egypt's imports are likely to be affected by the levels received under US food aid programs (e.g., PL 480), of which it is a major beneficiary.

The Soviet Union and Eastern bloc countries which comprise Group II have experienced a decline in income growth as measured by the annual percentage change in net material product (1.9 percentage point increase from 1978 to 1979 compared with an average 6.3 point increase over 1971 to 1977 (UN 1980, p. 23). While five year plans differ among the centrally-planned nations, a commitment to increased availability of consumer goods and an improved diet (i.e., higher livestock product consumption) has appeared as a priority in most (Urban). However, the sustainable rate of increase in livestock production and in the derived feedgrain requirement in the face of faltering income growth is yet a matter for speculation. Grain use and production of grains vary within the group. Eastern Europe feeds as much corn as barley and rye combined, while the Soviet Union feeds more than four times as much wheat and barley as corn. Trade by Group II nations is conducted by state agencies whose purchases depend upon decisions embodied in five year economic plans. However, as Ryan and Houck point out, this arrangement does not necessarily rule out price responsive behavior. Foreign exchange constraints and changes in global economic conditions do feed back into the domestic economies, albeit slowly.

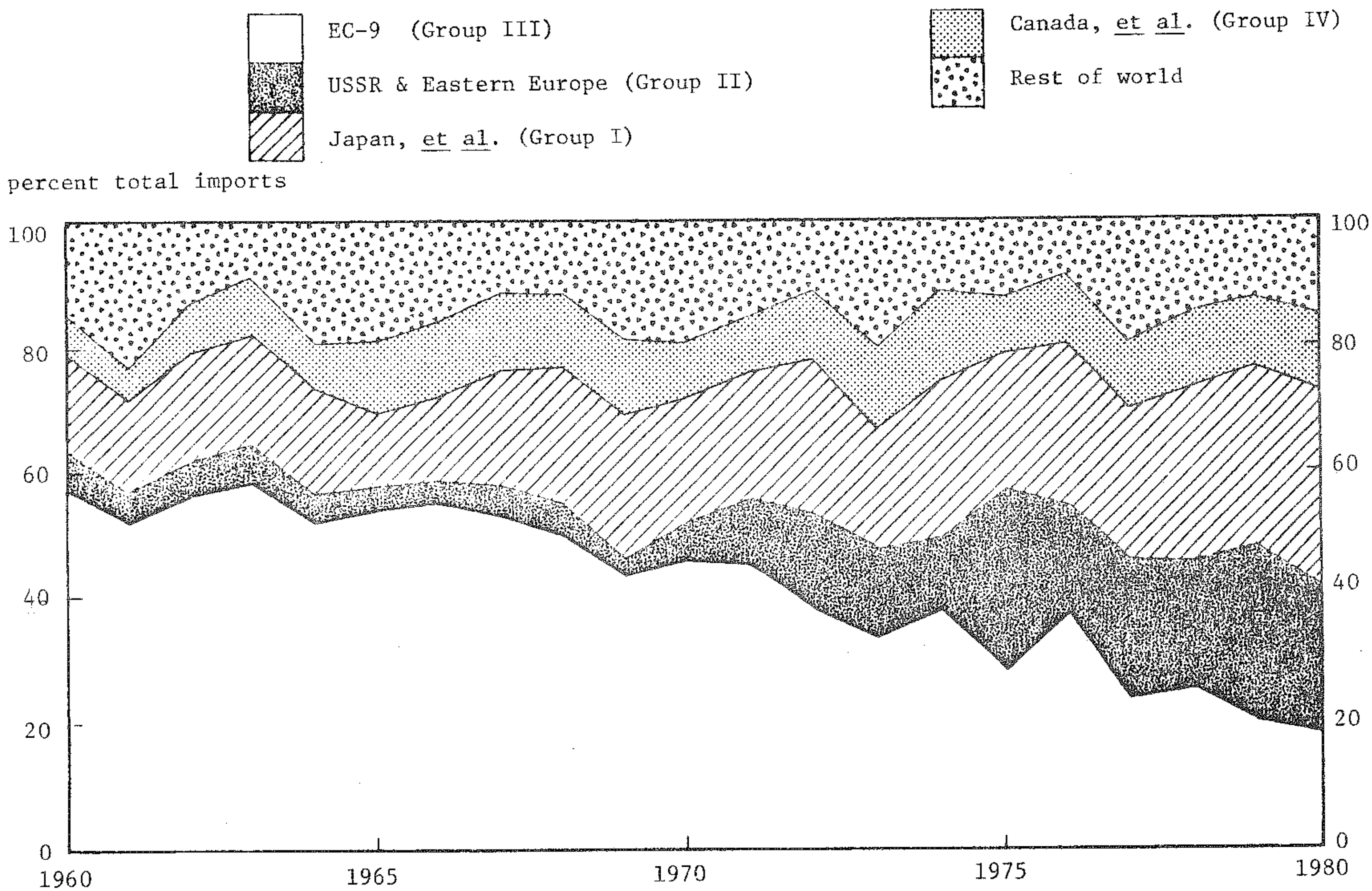
The first nine members of the European community, all affluent industrialized countries, comprise Group III. Corn is neither the dominant feedgrain produced or consumed in the EC-9. Barley usually represents around 38 percent of all grains fed, corn 32 percent and wheat 18 percent. Corn averaged 22 percent of coarse grain production over the past ten years and was

Table 4 Aggregation of major world corn importers

Group	1979/80 Corn Imports	Share of World Corn Imports
	(MMT)	(%)
Group I		
Mexico	3.9	5
South Korea	2.3	3
Taiwan	2.4	3
Malaysia	0.5	0.6
Israel	0.5	0.6
Egypt	0.5	0.6
Subtotal	9.6	12.8
Japan	11.9	15
Group I total	21.5	27.8
Group II		
Soviet Union	14.5	18
Eastern Europe	6.8	9
Group II total	21.3	27
Group III		
European Community	15.8	20
Group IV		
Spain	4.4	6
Portugal	2.4	3
Greece	1.2	1
Canada	1.0	1
Group IV total	9.0	11
Total All Groups	68.1	85.8
All others	10.5	14.2
World	78.6	100.0

Source: USDA OASIS Data Base

Figure 3 World corn import market shares 1960-1980



also less important than wheat production. The Common Agricultural Policy dictates that imports of corn (along with wheat, barley and the other feed-grains) be subject to a variable levy which is intended to protect internal support programs. By raising the price of imported corn to some minimum threshold level, the support, or intervention, price and the target, or desired wholesale price can be more easily defended or attained. This variable levy drives a wedge between world price and community price, a differential which in turn affects the decisions of EC-9 importers.

Spain, Portugal, Greece, and Canada are the four countries in Group IV. Each can be considered to fall into the developed nation category according to income levels, although Canada would be more affluent than the others. The hallmark of these nations' behavior has been their steady share in the world corn market. Although there is heterogeneity in corn production patterns and trade policies among the four, the historical steadiness of their respective market shares justifies their aggregation.

The remaining 15 percent of world corn exports not accounted for by Groups I through IV goes to a group of steady small importers (e.g., the Philippines) and a more volatile group of participants. The PRC is the most significant sporadic purchaser, importing no corn in 1976/77, 3 MMT in 1978/79 and 1 MMT in 1980/81. Exceptionally large Chinese purchases in 1961/62 and 1973/74 are reflected in sharply larger market shares for the rest of world (ROW) category in those years.

Over 80 percent of the corn produced in the United States is grown in the section of the Midwest known as the Corn Belt. The ten leading corn producing states are, in order, Iowa, Illinois, Nebraska, Indiana, Minnesota, Ohio, Wisconsin, Michigan, Missouri, and South Dakota. Not coincidentally, large amounts of livestock are raised in the same region; in 1979, 65 percent of all US hogs, 42 percent of all dairy cattle, and 25 percent of all beef cattle were produced in the Corn Belt (USDA 1980a, various pages).

Corn is often grown in rotation with soybeans because of the legume's nitrogen contribution to the soil (Pierre, Aldrich, andMartin, p. 14). Relative prices of the two crops influence farmers' planting decisions along with rotational needs. The extensive use of both corn and soybeans (in the form of high protein meal) in livestock production enhances the importance of their relationship relative to the feed concentrate market.

In 1979/80, corn area harvested for grain was 29.5 million hectares (73 million acres), higher than any year since 1960/61 when about 30 million hectares were harvested. In between these extremes, there appears to have been two types of behavior. In the 1960s, area harvested fluctuated between about 22 and 26 million hectares (55 and 65 million acres). The next decade saw the beginning of a more noticeable upward trend, although this period was ushered in by the sharp decline of the 1970/71 corn blight. The blight had severe effects; 27 million hectares were planted but only 23 million harvested. Average yield dropped to 4.54 MT per hectare (72.4 bushels per acre), compared with 5.39 in 1969/70 and 5.53 in 1971/72 (USDA 1980a, p. 30). The broader behavior pattern of corn acreage can be explained by government support programs, market conditions, and weather.

The sharp decline in area planted from 1960/61 to 1961/62 growing seasons appears primarily attributable to a change in the government feedgrain support program in the face of large reserves and low market prices. Under this program,

> ...cooperating producers were required to divert land from (corn and sorghum) to conserving uses as a qualification for obtaining price support loans. To induce compliance, a payment from the government was made for idling this land; it was called an acreage diversion payment.
>
> (Cochrane and Ryan, p. 188)

Following the institution of this program, feedgrain production was less than consumption for the first time in ten years. Stocks were reduced by about 12 MMT and market prices rose. Over the remainder of the decade there was little change in the level of overall support although the relative contributions of loan rate and direct payments fluctuated (Cochrane and Ryan, p. 199). Thus, the constancy in area planted over the 1960s appears in large part due to the constancy of government support levels as well as to the absence of any catastrophic weather or diseases.

While the corn blight inaugurated the 1970s, the following year saw the first major change in government feedgrains policy since 1961.

> As before, a government payment was authorized for cropland diverted to a conserving use, but the diversion did not require a reduction in acreage planted to any particular crop. The diverted acreage was called 'set aside'.
>
> (Cochrane and Ryan, p. 201)

The set aside restrictions were relaxed as the 1970s wore on, as a result reduced crops due to dry weather from 1973/74 to 1976/77, with a particularly poor crop in 1974/75, coupled with buoyant export demand. No corn acreage was set aside or diverted in the 1975 through 1977/78 crop years. Two and one-half million hectares were set aside in 1978/79 and 1979/80 (USDA 1980a, p. 13). Stocks had been drawn down to very low levels in the middle part of the decade but began to climb again, although prices stayed strong enough to forestall the reintroduction of set aside rules through the end of the seventies.

Given the upward trend in corn area planted, it is logical to ask whether this expansion can be expected to continue. As of November 1979, 14.6 million hectares were estimated to have a high probability of being converted to cropland and another 36.8 million hectares of medium probability (OTA, p. 57). Since there are no quantitative statements about price or market conditions which accompany these conversion probabilities, they can best be taken as a first guess. Further, it is not clear how much of this generally marginal land would be suitable for corn, even if improvements were made (e.g., irrigation).

Corn yields in the United States have risen from an average 2.51 MT per hectare (40 bushels per acre) at the close of World War II to 6.84 (109 bushels) in 1979/80 (USDA 1980a, p. 30). This persistent upward trend is broken significantly at two junctures. These drops, in 1970/71 and 1974/75, can be ascribed to the influence of corn blight and bad weather (drought), respectively. The general increase in yields can be attributed to genetic improvements in corn characteristics through the introduction of hybrid varieties and to improved husbandry practices. "The management tends to reduce the environmental stresses, while hybrids are developed that are less sensitive to adverse environmental factors that can be controlled (e.g., fertilizers, weed control, insect control, etc.)" (OTA, p. 53). The OTA is of the opinion that since "current fertilization practices have reached near optimum rates," yields will not continue to increase at the rate of the past 30 years (p. 53).

Favorable weather, as well as improved technology and husbandry, contributes to higher yields. The correlation between low yields and bad weather makes this point. Variation in corn yields can be explained well by meteorological influences. Yields in the Corn Belt appear "very sensitive to high maximum temperatures and prolonged dry periods, especially during pollenation," according to Benci and Runge (p. 282). Further, they report that

> (B)ased on approximately seventy years of historical weather data, corn yields decreased approximately 14% for a combination of 1°C increase in average weekly maximum temperature and a 10% decrease in precipitation. Results from (their model's) predictions also indicate that from 1930-72 a trend towards favorable weather events existed which alone explains 36% of yield variability.
>
> (p. 282)

The Benci and Runge model enables short run (within a growing season) prediction of yields once important factors, such as soil moisture and temperature pattern, are known. In an economic model with annual period, these variables are not incorporable. So, even though it is possible to derive a weather index that explains yield well in retrospect, there is no comparable technique for predicting the weather. Lu and Quance note that accurate prediction would be a boon to agricultural productivity, but state that "... given the present state of knowledge, it is unlikely that such technological breakthroughs will occur by the year 2000" (p. 6). Their estimate seems somehow sanguine. Nonetheless, guesses about future yield levels must be tempered by an appreciation of the influence of the weather and the possibility that it has lately been usually favorable.

Although corn accounts for over 80 percent of all feedgrain disappearance, only about 55 percent of feedgrain stocks are held as corn. Indeed, compared to those of all grains, stocks for corn have been a smaller percent of available supply for the past twenty years. The stocks to use ratio for corn (and sorghum as well) has averaged about 15 percent in contrast to 47 percent for wheat, 50 percent for oats and for barley. Although affected by the same government policies as other grains, corn stocks have not overhung the market. Since 1965, private stocks have averaged about 14 percent of annual use and government stocks for only about 3 percent (in the years when stocks were held at all, being zero from 1973/74 through 1976/77).

Prior to 1977, stocks of corn were acquired by the Commodity Credit Corporation (CCC) as a consequence of the support program, the level of accumulation dependent on the relationship between the legislated loan rate and the market price. Minimal stocks were accumulated during the seventies because usually the market price stayed well above the loan rate. The Food and Agriculture Act of 1977 included a provision authorizing the institution of a farmer owned reserve (FOR) for feedgrains, similar to that mandated for wheat and rice in the same bill. The FOR represents the "first serious US experience with a managed, national reserve program" (Meyers and Ryan, p. 316).

The FOR for corn sets up a system which makes stock accumulation and release potentially more sensitive to price movements. In addition to the nine month nonrecourse loans available to eligible farmers, the FOR provides three-year loans with an annual storage subsidy approximately equal to commercial storage costs in the major corn producing states (Meyers and Ryan, p. 316). This FOR corn is then subject to a set of redemption rules dependent on the relationship between market price and a series of specified price levels. At the lowest level is the loan rate, which still acts to put a floor under market price. The release level, at which reserve grain may be redeemed, and the call level above that, at which it must be redeemed, are set at fixed percentages above the annual loan rate. The Secretary of Agriculture has some discretionary authority over the terms under which grain may be placed in the FOR (such as waiving interest payments on storage subsidies, as after the Soviet embargo); these may be used to provide farmers with further incentive or disincentive to store corn.

The FOR has been in place, then, since 1977. Meyers and Ryan identify its main objectives as price stabilization within a broad range and increased reliability of US export and domestic supplies. In an evaluation of FOR operation over its first three years, they find that, for wheat and corn,

> ...the elimination of the FOR results in a higher price variance, lower total stocks, lower reserve levels, and higher free stocks. Effects on production over this period were relatively small, but the changes in stock levels were substantial. Without the FOR, grain stocks as a percentage of utilization in 1980/81 would approach the levels experienced in 1973/74 for corn and 1974/75 for wheat, and all reserves would be exhausted.
>
> (p. 321)

To increase price stability for livestock producers, the call and release levels for corn have been set in a more narrow band than that for wheat. While this causes more frequent changes in the status of FOR corn, which irritates corn producers who would like to see the call price abolished, it represents the first time the grains/livestock linkage has been incorporated.

If the FOR has been judged fairly effective at price stabilization, it would seem less successful as an adequate supply assurance mechanism. The goal for total corn carryover was set at about 38 MMT (Meyers and Ryan, p. 316). In 1980/81, stocks were drawn down to 26 MMT and would have been lower had the FOR not absorbed much of the embargoed corn the previous year. While stocks are expected to reach the 38 MMT level in 1981/82, after a bumper harvest, it is not clear that the FOR can consistently assure this minimum level.

The 1981 farm bill extended the FOR provision through 1985, establishing a lower limit for the feedgrain reserve of 25 MMT (1 billion bushels). Otherwise, the basic operating rules remain essentially the same as at the FOR's inception. The Secretary has the discretion to set both the release and the call levels, and, when price has reached these levels, to "increase the rate of interest on loans that have been made and design other methods to encourage the orderly marketing of wheat and feedgrains" (Johnson, Rizzi, Short, and Fulton, p. 18).

Over the past decade, the US held an average 55 percent of total world corn ending stocks. Since the US produces about the same proportion of all world corn each year, this mean level is not disproportionate. US stocks, while of modest size relative to supply, have been much more variable than those of the rest of the world. US stocks in the 1970s had a standard deviation of 10 MMT, which represents 50 percent of their mean level of 20 MMT. In contrast, total corn stocks abroad over the same period averaged 15 MMT and showed a standard deviation of 1.5 MMT, about ten percent of the mean. This discrepancy arose as US stocks were drawn down in response to world shocks and the US became the residual supplier. As noted earlier, government stocks were depleted at mid-decade.

As is the case within the US, coarse grain stocks are not as large as those of wheat, a foodgrain, where size is measured by the average ratio of stocks to supply. The figure for world coarse grains was 11 percent and for wheat 21 percent, averaged over the 1970s. The historical level of stocks of coarse grains was not sufficient to prevent large gyrations in the price of corn, the only feedgrain traded in appreciable quantities internationally. Since feedgrain stocks worldwide are relatively small, and since the US is the residual supplier in the event of a shortfall, the ability of stocks to buffer shocks in the future will depend on the levels held by the US. A 25 MMT minimum on the feedgrain FOR, in the absence of expansion of commercial holdings, probably means that the stocks to use ratio over the 1980s will not be significantly higher than it was in the 1970s. Should market shocks recur, price instability may thus again be the result in the absence of an adequate buffer reserve.

MODEL SPECIFICATION AND ESTIMATION

The specification and estimation of the empirical corn and livestock model are presented along with an evaluation of the model's validation over the historical period. A brief overview of the previous research on similar models is followed by a description of the model's logical structure. Each of the components of the model is subsequently described in more detail. The results of the historical simulation and an appraisal of the model's performance appear next.

Review of previous research

Over the past fifteen years, a number of efforts have been made at modeling various aspects of the feedgrain and livestock sectors and their interdependencies. These studies can be roughly divided into those which focus primarily on feedgrains, on livestock, and on the integrated feedgrain-livestock economy. The works reviewed here do not necessarily comprise an exhaustive list but rather are those which appear most relevant to the present model. The models are examined in a general way; later, more detailed reference is made to some of them in the discussion of the specification of the empirical model.

Major works on the US feedgrain sector are by Ahalt and Egbert (1965), Meilke (1975), and Womack (1976). Ahalt and Egbert's study of the demand for feed concentrates covers the period 1947 to 1963 and uses highly aggregated data to explain the domestic feed consumption of total concentrates as well as low- and high-protein concentrates and feedgrains. Livestock production and grain consuming animal units are exogenous to the model. The major conclusion of the study was that economic factors, such as the product-feed price ratio, explained the large post-war increases in concentrate consumption levels. They note, "Although technological developments are changing feed conversion rates, the actual levels of feeding depend heavily on the economic forces facing the livestock producer" (p. 41). Although the model is highly aggregated and its results now outdated, it is significant because of its initial identification of the major economic factors affecting the demand for feed concentrates in the US livestock sector.

Meilke's study aggregates the four feedgrains in a six-equation linear model to explain their four major utilizations (livestock feed, food and industrial products, exports, and stocks), their price (in index form), and the number of grain consuming animal units on feed. Production, imports, and seed use are treated as predetermined in the model, which runs from 1945 to 1972. As is the Ahalt and Egbert study, Meilke's is highly aggregated and as such does not consider demand by separate livestock sectors or export demand by individual countries or groups of countries. Meilke does explain the acquisition of commercial and government stocks (taken together) endogenously. The number of grain consuming animal units on feed is a simple function of lagged feedgrain and livestock prices.

Womack's basic model explains the US demand for corn, sorghum, oats, and barley. The model, covering 1948 to 1972, has separate feed, stock, and food demand equations for each feedgrain, with production and exports predetermined (although these variables are later incorporated endogenously using the results of work by Houck and others). As in other models, feedgrain demand is not disaggregated by livestock category. A peculiar feature of the feed demand equations is that the value aggregate of livestock production is used as an explanatory variable, as opposed to an index of physical production or grain producing animal units. Womack's analysis is clearly derived from theory and represents the most comprehensive model of feedgrain demand to date.

Freebairn and Rausser (1975) present a model of the livestock sector (1956 through 1971) which explains consumer demand, producer and retail price relations, and livestock production and supply. Feedgrain prices enter the model exogenously and feed consumption levels are not explicitly considered. However, their results are significant in that they provide a disaggregated analysis by livestock sector, a description which is useful in considering the derived demand for feedgrains as a factor in production.

Richardson and Ray (1977) and Arzac and Wilkinson (1979a) have developed models which integrate the feedgrain and livestock sectors to varying degrees. Richardson and Ray examine the demand for feedgrains and concentrates by livestock category, although feedgrains are treated as a group. The disaggregation by livestock category is important "(S)ince ration flexibility varies considerably by type of livestock, the elasticities or other economic parameters for the separate feed demand relationships are likely to differ markedly across livestock categories" (p. 23). Such a formulation allows explicit recognition of the fact that "feed demand responds to changes in the mix of livestock produced, as well as to short run adjustment in the feed ration in response to changes in the relative price of feed and prices received for individual livestock categories" (p. 25). Thus, aggregate equations give an average response without consideration of changes in livestock production or supply, information useful in evaluating the impacts of policy actions. Their analysis treats all other aspects of the livestock and feedgrain markets (including prices) as exogenous, but makes a significant contribution in its recognition of the importance of disaggregation.

Arzac and Wilkinson (1979a) present a model of the US livestock and feedgrain sectors over the period 1960 to 1975. Unlike the other models discussed, theirs is quarterly, although endogenous feedgrain production (actually only corn) enters annually. The 42 equation linear model explains the demand and supply for fed and nonfed beef, pork, chicken, and corn. Demand for corn is explained not by livestock sector but by a single equation which has as explanatory variables the number of animal units on feed, corn price, and real disposable income. Corn price is explained as a function of commercial stocks size, exports, lagged corn price, and quarterly dummy variables. Stocks are determined as a residual by the model and exports are exogenous. Acreage planted and annual corn supply complete the specification of the endogenous corn sector.

Ospina and Shumway (1979) perform an analysis of short run beef supply response which includes the effects of grain price changes on beef price, supply, and composition. They address the empirical issues involved in modeling supply response for cattle, which are both consumption and capital goods (the same idea is also applicable in hog production). Their analysis disaggregates beef production by type of animal (steer, heifer, or breeding herd cull) and grade of carcass (choice, good, standard, or utility). This breakdown demonstrates the effects that the beef product mix has on feed use, since grade is at least partially determined by the amount fed to the animal.

The model in brief

The structure of the model (as shown in Figure 4) reflects the configuration of the corn market. Hog, beef, and broiler production are explained endogenously, product prices being determined at the wholesale level of demand. The demand for feed corn is derived from these livestock production levels. Stocks and other domestic disappearance, as well as US corn production, are also determined within the model. The demand for corn on the world market is incorporated through the aggregation of major importers into four groups with similar importing characteristics.

The empirical model contains 53 equations, of which 35 are behavioral equations and 18 are identities. Over half explain livestock production and consumption. It is estimated over the period 1961/62 to 1978/79. The final year of the seventies, 1979/80, is not included because the imposition of the Soviet grain embargo resulted in anomalous behavior in all sectors. The model is annual in period, except for the hog production sector, which is semiannual. The corn crop year, from October 1 to September 30, defines the annual period. Data available only on a calendar year basis are lagged one year to coincide with the appropriate crop year.

In Table 5, the model is written in implicit form. Also given is a list of the variable name definitions. These variable names will be used in the presentation of the empirical results.

Demand for livestock products

The interaction between the demand for livestock products and the supply determines the overall production level on which the derived demand for corn ultimately depends. For completeness, the demand side is included as an endogenous sector in the model. Five equations comprise the demand sector, one equation each for fed beef, nonfed beef, and broilers, and two for pork, one for each six month production period.

The main hypothesis behind the specification of the structural equations is that, within a specified period, the supply of livestock products is largely fixed, so prices, not quantities, adjust to clear the market. The demand equations should thus be price dependent. The period of fixed supply is one year for beef cattle and six months for hogs. The assumption that broiler supply is predetermined annually is less tenable, but the difficulties in modeling due to the shorter-than-six-month broiler production cycle and rapid technological change make the annual framework the best alternative.

Stocks of livestock products are ignored in the specification of the empirical model. In an annual framework, stocks are a stable and small percentage of supply. Beginning stocks of all meats (poultry excluded) in 1980

Figure 4 Model components

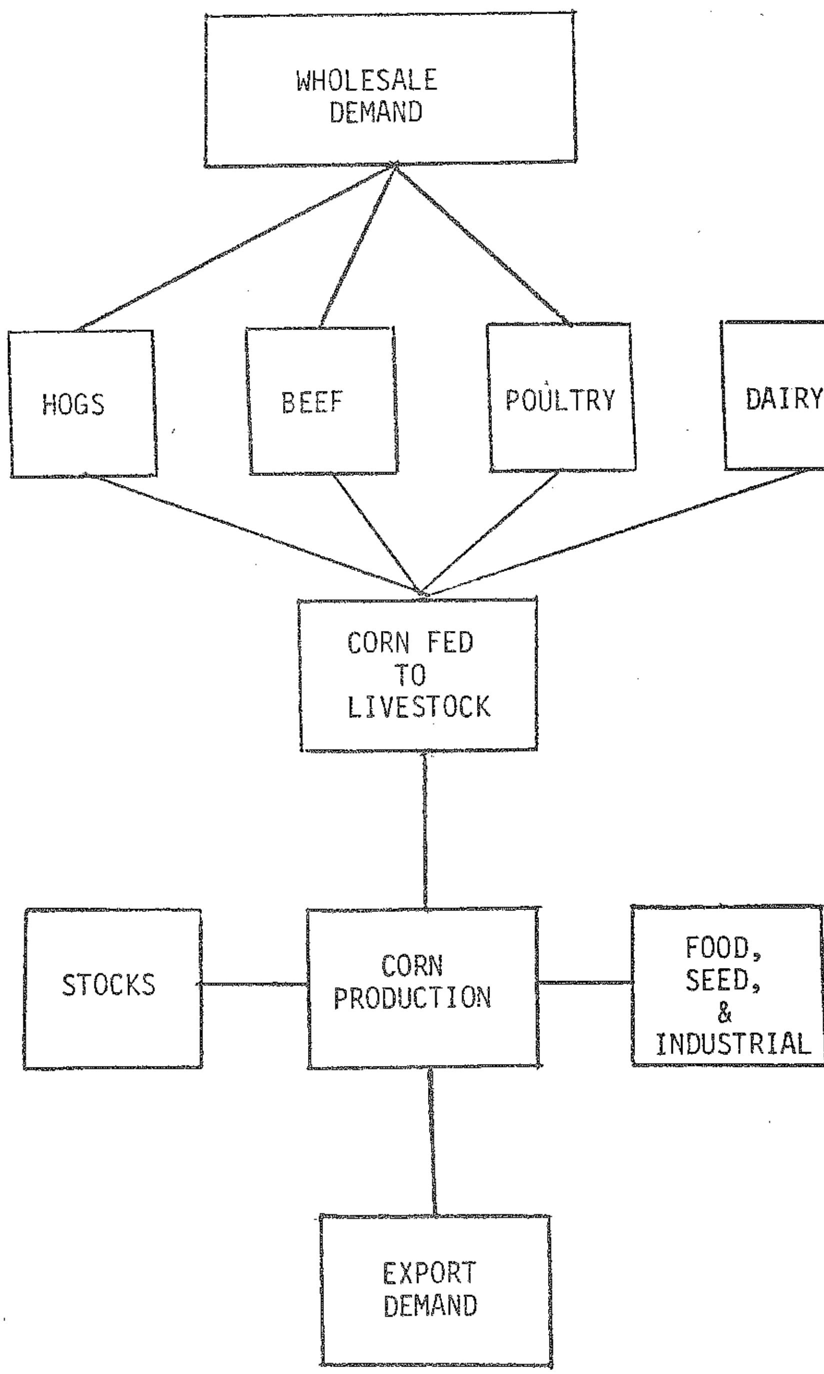


Table 5 . The model in implicit form

Equations

Wholesale level of consumer demand

(1) FBCPUS = f(FBCONPC, NFBCONPC, PKCONPC, DPIUSPC)

(2) NFBPUS = f(NFBCONPC, FBCONPC, PKCONPC, DPIUSPC)

(3) POPFMUS = f(BRCONPC, NFBCONPC, PKCONPC, DPIUSPC)

(4) BGPFUS1 = f(PKCONPC1, NFBCONPC/2, DPIUSPC/2)

(5) BGPFUS2 = f(PKCONPC2, NFBCONPC/2, DPIUSPC/2)

Disappearance identities

(6) FBCONPC == FBPRDUS/POPUS

(7) NFBCONPC == NFBPRDUS/POPUS

(8) PKCONPC1 == (BGSLUS1 + SOWSLUS1) * HGAVDWT / POPUS

(9) PKCONPC2 == (BGSLUS2 + SOWSLUS2) * HGAVDWT / POPUS

(10) PKCONPC == PKCONPC1 + PKCONPC2

(11) BRCONPC == BRPRDUS * 0.72 / POPUS

Livestock production

Beef

(12) 0 == BFCOWINV - BFCOWINV(-1) + COWSLUS(-1) - HFADD(-1)

(13) CLFCROP = f(BFCOWINV, DLIQ*BFCOWINV)

(14) HFADD = f(BFCOWINV, FCPKCUS/PPIUS)

(15) NETCROP == CLFCROP(-1) - CLFSLUS(-1) - CLFDLOSS(-1) - HFADD(-1)

(16) COWSLUS = f(FCPKCUS/PPIUS, BFCOWINV, DLIQ*BFCOWINV)

(17) FCPKCUS/PPIUS = f(FBCPUS(-1)/COPFUSDT, D72)

(18) FBSLUS = f(NETCROP, DLIQ*NETCROP, FBCPUS(-1)/COPFUSDT)

(19) NFBSLUS = f(FCPKCUS/PPIUS)

(20) FCAVLWT = f(FBCPUS(-1)/COPFUSDT, D68, D71)

(21) FBAVLWT = FCAVLWT / 0.66 * 100

(22) FBPRDUS == FBSLUS * FBAVLWT * 0.62

(23) NFBPRDUS == (NFBSLUS + COWSLUS) * NFBAVDWT

Table 5 The model in implicit form (continued)

Equations
Hogs
(24) 0 == HGBINV2 - HGBINV2(-1) + SOWSLUS2(-1) + SOWSLUS1 - GADD2(-1) - GADD1
(25) SOWFAR1 = f((HGBINV2(-1) - SOWSLUS2(-1) + GADD2(-1)), DLIQ*(HGBINV2(-1) - SOWSLUS2(-1) + GADD2(-1)))
(26) SOWFAR2 = f(HGBINV2, D6874*HGBINV2)
(27) PCROP1 = f(SOWFAR1)
(28) PCROP2 = f(SOWFAR2)
(29) BGSLUS1 = f(PCROP2(-1))
(30) BGSLUS2 = f(PCROP1)
(31) SOWSLUS1 = f((HGBINV2(-1) - SOWSLUS2(-1) + GADD2(-1)), BGPFUS2(-1)/PPIUS, COPFUSDT/PPIUS, D75)
(32) SOWSLUS2 = f(HGBINV2, D6872*HGBINV2, BGPFUS1/PPIUS, COPFUSDT/PPIUS)
(33) GADD1 = f(SOWSLUS1, BGPFUS2(-1)/PPIUS, COPFUSDT/PPIUS, D69)
(34) GADD2 = f(SOWSLUS2, D6975*SOWSLUS2, BGPFUS1/PPIUS, COPFUSDT/PPIUS)
Broilers
(35) BRPRDUS = f(POPFMUS/COPFUSDT, TIME)
Corn disappearance
Livestock
(36) CBEEFUS = f (FBPRDUS, D72, D73)
(37) CHOGSUS1 == CHOGAV * (BGSLUS1 + SOWSLUS1)
(38) CHOGSUS2 == CHOGAV * (BGSLUS2 + SOWSLUS2)
(39) CPOLTUS = f(COPFUSDT/POPFMUS, BRPRDUS)
(40) CDAIRUS = f(TIME, D70, D71)

Table 5 The model in implicit form (continued)

Equations

Food, seed and industrial use

(41) CFOODUS =f(CFOODUS(-1))

Stocks

(42) CSTKTUS = f(COPLDT/COPFUSDT, CPRDUS, CSTKTUS(-1))

World corn imports

(43) CIMPI = f(LVSTKI)

(44) CIMPII = f(CGPRDII, LVSTKII, COPFUSDT/WLDCPI)

(45) CIMPIII = f(CGPRDIII, LVSTKIII, D76)

(46) CIMPIV = f(TIME)

US corn production

(47) COAPLUS = f(COPFUSDT(-1)/SOYPUSDT(-1), COAPLUS(-1), COASAUST)

(48) COAHUGS = f(COAPLUS)

(49) CYLDGUS = f(PP7PZ, TIME, D70, D74)

(50) CPRDUS == COAHGUS * CYLDGUS

Market clearing identities

(51) CLVSTKUS == CBEEFUS + CHOGSUS1 + CHOGSUS2 + CPOLTUS + CDAIRUS + COLVSUS

(52) COUXTUS == CIMPI + CIMPII + CIMPSU + CIMPIII + CIMPIV + CIMPROW - COUXTROW

(53) 0 == CLVSTKUS + CFOODUS + CSTKTUS + COUXTUS - CIMPUS - CPRDUS - CSTKTUS(-1)

Table 5 The model in implicit form (continued)

Variable definitions	
Endogenous	
BFCOWINV	beef cow inventory January 1 (million head)
BGPFUS1	barrow and gilt price, average December to May ($/100 lbs)
BGPFUS2	barrow and gilt price, average June to November($/100 lbs)
BGSLUS1	barrow and gilt slaughter, December to May (million head)
BGSLUS2	barrow and gilt slaughter, June to November (million head)
BRCONPC	broiler consumption per capita (pounds)
BRPRDUS	broiler production, liveweight (billion lbs)
CBEEFUS	corn fed to beef cattle (million metric tons (MMT))
CDAIRUS	corn fed to dairy cattle (MMT)
CFOODUS	corn used for food, seed, and industry (MMT)
CHOGSUS1	corn fed to hogs, December to May (MMT)
CHOGSUS2	corn fed to hogs, June to November (MMT)
CIMPI	total corn imports by Group I (MMT)
CIMPII	total corn imports by Group II (MMT)
CIMPIII	total corn imports by Group III (MMT)
CIMPIV	total corn imports by Group IV (MMT)
CLFCROP	calf crop (million head)
CLFDLOSS	calf death loss (million head)
CLVSTKUS	corn fed to all US livestock (MMT)
COAHGUS	corn area harvested (million hectares)
COAPLUS	corn area planted (million hectares)
COPFUSDT	corn price, season average to farmers ($/MT)
COUXTUS	corn exports by US (MMT)
COWSLUS	cow slaughter (million head)
CPOLTUS	corn fed to poultry (MMT)
CPRDUS	corn production US (MMT)
CSTKTUS	total corn stocks US (MMT)
CYLDGUS	corn yield US (MT/hectare)
FBAVLWT	fed beef average liveweight (lbs)

Table 5 The model in implicit form (continued)

Variable definitions	
FBCONPC	fed beef consumption per capita (lbs)
FBCPUS	fed beef cattle price ($/100 lbs)
FBPRDUS	fed beef production (million lbs)
FBSLUS	fed beef slaughter (million head)
FCAVLWT	feeder cattle average liveweight (100 lbs)
FCPKCUS	feeder cattle price ($/100 lbs)
GADD1	gilts added, December to May (million head)
GADD2	gilts added, June to November (million head)
HFADD	heifers added (million head)
HGBINV2	hog breeding inventory, June 1 (million head)
NETCROP	net calf crop (feeder cattle supply) (million head)
NFBCONPC	nonfed beef consumption per capita (lbs)
NFBPRDUS	nonfed beef production (million lbs)
NFBPUS	nonfed beef price ($/100 lbs)
PCROP1	pig crop, December to May (million head)
PCROP2	pig crop, June to November (million head)
PKCONPC	pork consumption per capita (annual) (lbs)
PKCONPC1	pork consumption per capita, December to May (lbs)
PKCONPC2	pork consumption per capita, June to November (lbs)
POPFMUS	broiler price to farmers ($/100 lbs)
SOWFAR1	sows farrowing, December to May (million head)
SOWFAR2	sows farrowing, June to November (million head)
SOWSLUS1	sows slaughtered, December to May (million head)
SOWSLUS2	sows slaughtered, June to November (million head)

Table 5 The model in implicit form (continued)

Variable definitions	
Exogenous	
CGPRDII	coarse grain production Group II (MMT)
CGPRDIII	coarse grain production Group III (MMT)
CHOGAV	corn fed per hog, average (MT)
CIMPROW	corn imports by the rest of the world (MMT)
CIMPSU	corn imports by the Soviet Union (MMT)
CLFSLUS	calf slaughter (million head)
COASAUST	corn area set aside US (million hectares)
COLVSUS	corn fed to other livestock US (MMT)
COPLDT	corn loan rate US ($/MT)
COUXTROW	corn exports by the rest of the world (MMT)
DLIQ	dummy for cattle cycle (1974/75 to 1978/79 = 1)
DPIUSPC	disposable personal income per capita US ($1000)
D68, etc.	dummy for year indicated
HGAVDWT	hog average dressed weight (lbs)
LVSTKII	livestock production Group II (million pounds)
LVSTKIII	livestock production Group III (million pounds)
NFBAVDWT	nonfed beef average dressed weight (lbs)
POPUS	population US (millions)
PPIUS	producers prices paid index US (1967 = 100)
PP7PZ	fertilizer price index US (1967 = 100)
SOYPUSDT	soybean price US ($/MT)
TIME	time, linear trend (1961/62 = 1, ...)
WLDCPI	world consumer price index (1970 = 100)

comprised only two percent of supply (USDA 1981 , p. 118). The need for refrigeration makes meat storage expensive and stockholding negligible. The limited role for stocks implies that, with production largely fixed, demand will determine livestock prices.

The price dependent specification of the demand equations is justifiable as being an accurate representation of livestock product markets but is also consistent with utility maximizing consumer behavior (Heien, p. 128). Quantity-dependent demand equations are derived from utility maximization problems in which quantities of goods appear as the arguments of the utility function. The same underlying preference ordering can be represented by replacing the quantities in the utility function by their optimal values to obtain the indirect utility function (Phlips, p. 27). The indirect utility function has prices and income as arguments. Demand equations derived from its maximization are price-dependent, with quantities and income on the right hand side. Prices and income are normalized on the prices of all goods when it is assumed that consumers do not suffer from money illusion.

The markets for beef and pork (and to a lesser extent broilers) have three levels: farm; wholesale; and retail. While all these prices are closely related, they are separated by spreads, or marketing margins. Gardner argues that margins cannot be explained by a simple markup pricing rule (as in Freebairn and Rausser and Arzac and Wilkinson) because "these prices move together in different ways depending on whether the events that cause the movement arise from a shift in retail demand, farm supply, or the supply of marketing inputs" (p. 406). If Gardner is correct, then neither simply explaining margins with prices (e.g., retail as a function of wholesale price) nor imposing the margins exogenously will provide an accurate depiction of market pricing relationships. In this study, the lower levels of market interaction are selected for explicit consideration because of the difficulty in explaining the various margins endogenously and because these appear to be the competitive interfaces in the markets. Crom explains,

> Consumers patronizing retail stores are price takers and quantity adjusters; their demand is reflected through the quantities they purchase. Since the buyers representing retail distribution organizations bargain with salesmen representing meat packers and meat processors, the wholesale market level probably represents a true interaction of supply and demand forces in a bargaining sense.
>
> (p. 17)

Consequently, the retail price level, although closely linked to the other prices, is not included in this model.

There is evidence that, at least in the beef sector, retail prices are more stable than either those at the wholesale or farm level. Furthermore, "(R)etail beef prices are found to respond more slowly to wholesale price changes than wholesale beef prices respond to changes in farm prices" (Hall, et al., p. 22). Statistically, the correlation between farm and wholesale prices for livestock products is very close to positive one but substantially lower for wholesale and retail prices. So, in this model, farm price is the specified price variable but it functions as a proxy for wholesale price since physical quantities appear in terms of carcass (wholesale) not live (farm) weight. This formulation is necessary to capture improvements in production conversion efficiency over the past twenty years, particularly in the hog sector.

In the five structural demand equations, then, price depends on the quantities available for consumption of the product whose price is being considered as well as on the quantities of its potential substitutes and complements. Disposable income is also included as a regressor. All quantity variables and disposable income are in per capita terms. This transformation is required to alleviate the multi-collinearity present in the data due to trending consumption over the historical period.

The statistical results are, in general, similar to those of the market at the retail level provided by other studies in terms of magnitudes of price flexibilities and identification of substitution relationships among livestock products. In price-dependent equations, a negative sign on the quantity consumed of another livestock product indicates a substitution relationship, while a positive sign indicates a complementary one. The direction of signs cannot be predicted a priori, and, indeed, previous empirical work has yielded a variety of results (of which Bain provides a useful summary, p. 87). The estimated coefficients, their standard errors (in parentheses), the coefficient of determination, the Durbin-Watson "d" statistic (both only where valid), and the method of estimation (OLS or GLS) are given with each equation.

Livestock product price is hypothesized to be a function of own quantity consumed, quantities of other products consumed, and disposable income. In all equations, prices and income appear in nominal, not deflated, form. The large value of the t-statistic on undeflated disposable per capita income (DPIUSPC) made the hypothesis of no money illusion suspect. The sign on the income coefficient is expected to be positive since livestock products are probably normal goods. Fed beef price (FBCPUS) is a negative function of own quantity consumed (FBCONPC) and of nonfed beef (hamburger and cheaper cuts) consumed (NFBCONPC) and a positive function of per capita disposable income (DPIUSPC). The positive relationship between fed beef price and pork consumption (PKCONPC) probably does not mean that fed beef and pork are complements. Rather, the unexpected sign may be attributable to data peculiarities. Freebairn and Rausser report similar results and suggest they may be of "spurious nature" or that they "may be explained by preferences for variety in the meat menu" (p. 678), a less plausible conjecture. The large standard error on the pork coefficient here suggests that it might just as well be dropped.

$$
\text{(1)} \quad FBCPUS = \underset{(17.04)}{35.74} - \underset{(0.111)}{0.363} * FBCONPC - \underset{(0.122)}{0.432} * NFBCONPC + \underset{(0.208)}{0.091} * PKCONPC + \underset{(0.648)}{8.738} * DPIUSPC
$$

$\bar{R}^2 = 0.93$ DW = 1.08 OLS

As for nonfed beef price (NFBPUS), which represents the price of hamburger and other inexpensive cuts, it is explained by per capita consumption of nonfed beef (NFBCONPC), fed beef (FBCONPC), and pork (PKCONPC) and by disposable income (DPIUSPC). Nonfed beef consumption exhibits the expected substitution relationship with the other two meats. The price of hamburger determines the price for young, grass-finished steers and heifers and for cull cows, whose carcasses usually grade good or below.

$$
\text{(2)} \quad NFBPUS = \underset{(11.91)}{35.76} - \underset{(0.085)}{0.574} * NFBCONPC - \underset{(0.077)}{0.194} * FBCONPC - \underset{(0.145)}{0.088} * PKCONPC + \underset{(0.452)}{6.076} * DPIUSPC
$$

$\bar{R}^2 = 0.94$ DW = 1.62 OLS

Per capita consumption of broiler chickens (BRCONPC), nonfed beef (NFBCONPC), and pork (PKCONPC) and per capita disposable income (DPIUSPC) determine broiler price (POPFMUS). The three products appear to be substitutes.

$$
\text{(3)} \quad POPFMUS = \underset{(10.46)}{38.72} - \underset{(275.410)}{762.927} * BRCONPC - \underset{(0.551)}{0.039} * NFBCONPC - \underset{(0.109)}{0.192} * PKCONPC + \underset{(1.148)}{5.404} * DPIUSPC
$$

$\bar{R}^2 = 0.90$ DW = 1.50 OLS

In the equation explaining nonfed beef price (2), broilers do not appear as a substitute for nonfed beef, the relationship implied here. This apparently anomalous result can be reconciled with theoretical expectations in two ways. First, while the matrix of substitution effects derived from the utility maximization problem is symmetric, the influence of income effects may alter the relationships implied by the substitution matrix alone. Second, the fact that these equations represent total market movements raises questions of aggregation effects, which may distort relationships among goods at the micro or individual consumer level.

There are two equations to explain pork prices. Hog production is modeled on a semiannual basis, one period covering December to May, the other June to November. In each period, price must act to clear the market since pork supplies are almost perfectly inelastic. Pork quantity consumed per capita differs between the two periods because production differs, so per capita disappearance in each period is not the annual level divided in half. On the other hand, the relevant quantities of other products are represented by annual disappearance divided in half. This formulation is justified on the grounds that there is no marked seasonality in consumption of these products nor in disposable income. December to May pork price (BGPFUS1) (as represented by barrow and gilt price) is inversely related to its own disappearance (PKCONPC1) and positively related to that of nonfed beef (NFBCONPC/2) and to income (DPIUSPC/2).

$$\text{(4)}\quad BGPFUS1 = \underset{(12.71)}{51.31} - \underset{(0.305)}{1.372} * PKCONPC1 + \underset{(0.187)}{0.122} * NFBCONPC/2 + \underset{(1.191)}{10.544} * DPIUSPC/2$$

RHO = 0.75 GLS

However, nonfed beef and pork are most likely substitutes, so the unexpected sign may again be attributable to spurious data problems. June to November pork price (BGPFUS2) is a negative function of its own quantity (PKCONPC2) and, as expected, of nonfed beef (NFBCONPC/2). The sign on the income variable is positive, as expected.

$$\text{(5)}\quad BGPFUS2 = \underset{(12.71)}{96.51} - \underset{(0.272)}{2.585} * PKCONPC2 - \underset{(0.266)}{0.194} * NFBCONPC/2 + \underset{(2.694)}{9.180} * DPIUSPC/2$$

RHO = 0.80 GLS

At the sample means, calculated price flexibilities with respect to own quantity were -0.77 for fed beef, -0.69 for nonfed beef, -1.52 for broilers, and -2.0 for pork. A flexibility less (greater) than one means that a one percent change in quantity results in a less (greater) than one percent change in price. So, a flexible price (flexibility greater than one) implies that small changes in quantity provoke relatively large price changes, a situation which characterizes price inelastic demand. These estimated values imply that fed and nonfed beef markets are characterized by relatively elastic demand, particularly as compared to the pork and broiler markets with rather more price inelastic demands. These qualitative results are consistent with the findings of similar studies. In particular, Arzac and Wilkinson (1979a) (using retail prices) found own price elasticities of -1.86 and -2.97 for fed and nonfed beef, respectively, compared to values of -0.87 and -0.98 for pork and chicken, respectively (p. 299).

In all cases, income flexibilities at the sample means were positive, as expected, since an increase in income translates into increased consumption of normal goods (such as livestock products) and thus higher prices. These values were 0.93 for fed beef, 1.03 for nonfed beef, 1.16 for broilers, and a 12 month average 0.68 for pork. Consonant with other studies, fed beef and pork consumption are found to be relatively less responsive to changes in income than nonfed beef and chicken. Arzac and Wilkinson (1979a) report income elasticities of 1.02 and 0.65 for fed beef and pork, respectively, and 0.45 for nonfed beef and 0.52 for chicken (p. 299).

Identities (denoted by two equality signs) transform liveweight livestock production into per capita, carcass weight disappearance variables. Fed beef consumption per capita (FBCONPC) is the quotient of fed beef production (FBPRDUS), converted to carcass weight in another equation presented below, and US population (POPUS).

(6) FBCONPC == FBPRDUS/POPUS

Similarly, nonfed beef consumption per capita (NFBCONPC) is found by dividing nonfed beef production (NFBPRDUS), already converted to carcass weight, by population (POPUS).

(7) NFBCONPC == NFBPRDUS/POPUS

To find pork consumption per capita in each of the two semiannual periods, where December to May is denoted by the suffix 1 and May to November by 2, total barrow and gilt slaughter (BGSLUS) and sow slaughter (SOWSLUS) in each period is multiplied by the annual average dressed weight of hogs (HGAVDWT) and divided by population (POPUS). Hog dressed weight is entered as an exogenous vector to capture increase in dressing yields (percent of liveweight) over the years.

(8) PKCONPC1 == (BGSLUS1 + SOWSLUS1) * HGAVDWT / POPUS

(9) PKCONPC2 == (BGSLUS2 + SOWSLUS2) * HGAVDWT / POPUS

Although sows have somewhat different meat production characteristics than those of barrows and gilts, the two are combined here since sows are a small proportion, about six percent, of total annual slaughter. Total annual pork consumption per capita (PKCONPC), which appears in the other livestock product equations, is found as the sum of the two period's consumption.

(10) PKCONPC == PKCONPC1 + PKCONPC2

Per capita broiler consumption (BRCONPC) is expressed in terms of ready-to-cook weight, calculated as 72 percent of liveweight production (BRPRDUS), divided by population (POPUS).

(11) BRCONPC == BRPRDUS * 0.72 / POPUS

Livestock supply

Since the purpose of the model is ultimately to provide an accurate depiction of the relationships in the corn market, it is necessary to provide a plausible explanation of the derived demand which arises in the livestock production sectors. Consequently, beef, hog, and broiler production are explained endogenously in the model. Dairy production is taken as exogenous; the degree of government intervention in the market makes it difficult to model, especially in an aggregated form. The structural specification and estimation of the equations in each of the submodels is discussed in turn.

Beef supply

Changes in corn price affect beef production in both the short (within one year) and longer run. The empirical model allows explicit recognition of these dynamic relationships. Arzac and Wilkinson, Bain, Crom, Ospina and Shumway, and Freebairn and Rausser have all constructed models to explain events in the beef sector. Of these, that of Ospina and Shumway is most similar to the model presented here, in terms of level of disaggregation and approach to the definition of structural relationships. For this reason, reference is made to their results in providing a framework for discussion of the characteristics of the current model.

As Ospina and Shumway point out, econometric models of the beef sector have produced conflicting results on the magnitude and sign of supply elasticities. The most notable anomaly has been the negative or zero own current price elasticity for slaughter steers, the industry's primary output. In resolving these conflicts, three important issues in model specification have been identified by Ospina and Shumway: disaggregation according to animal class and quality components; differentiation between current and expected price effects on slaughter supplies; and simultaneity in slaughter supply, demand, and inventory accumulation decisions (p. 57). By recognizing the importance of each of these features to the task of the model at hand, the structural equation specification can be better appreciated.

The basic justification for disaggregation is the heterogeneity of beef products; sirloin and hamburger are produced in different ways (in particular, with different amounts of corn) and are not perfect substitutes from the consumer's point of view, either. Consequently, it seems reasonable to expect that the "class and quality composition of carcass beef undoubtedly changes in response to price changes" (Ospina and Shumway, p. 44). Their model disaggregates beef into three classes (steer, heifer, and breeding herd cull) and three quality categories (choice-prime, good, and standard and lower (utility)), which requires the construction of a good deal of data. In this study, beef supplies are separated into fed and nonfed components, a formulation which requires somewhat less heroic data manipulation but which is still adequate to capture differential price (both beef and corn) response. As will be seen, price changes affect not only the slaughter mix of fed versus nonfed beef, but also the final weights (and thus the quality) of animals which are placed in feedlots.

Current and expected prices may have differential effects on beef production. As Nelson and Spreen explain, this is because cattle are simultaneously capital goods and consumption goods (a point made earlier by Jarvis). "That is, as capital goods they possess the potential of converting inputs into a marketable product of a different form, but, at any time, they may be sold to slaughter as consumption goods" (p. 117). Consequently, with an increase in say feeder cattle price, the cow-calf producer must decide whether to sell heifers for slaughter or to retain them for breeding. This decision depends on his expectation of future price behavior relative to current price. It is this assessment that then affects both current (within a year) and future slaughter supplies. Feedlot operators must also make a similar judgement in determining how long to hold cattle on feed. Although this decision is made within a year (the feedlot stage is about four to six months long), its effect is to raise or lower the final weight of the slaughter animal, a phenomenon which can be captured empirically within the model's annual time frame. Previously observed negative own price response (Freebairn and Rausser) is attributed to the net effect of these differential price effects. In the current model, price expectations take on a naive form. Last year's price is taken as current expected price, since the model assumes beef production, through the supply of feeder cattle, to be largely fixed. Some adjustments may be made through alteration of final weights and the slaughter mix.

The final specification issue concerns the simultaneity involved in slaughter supply, demand and inventory decisions. Again, the dual capital/consumption good nature of cattle largely explains these relationships. As does Ospina and Shumway's, the current model incorporates these decisions endogenously, so that, in each year, the allocation of heifers and of cows between slaughter and the breeding herd is determined. These effects are carried forward and reflected each year in the supply of feeder cattle, which depends on the previous year's calf crop (a function of the size of the breeding herd), calf slaughter, death loss, and heifers added to the breeding herd. These inventory decisions are made by cow-calf producers with reference to the appropriate expected output price, that of feeder cattle. Own prices for heifers and cows are so closely related to feeder cattle price, that, due to problems of multicollinearity, only the latter is included in the inventory decision equations (cows slaughtered, heifers added).

The existence of a production cycle for beef cattle, about ten years from peak to peak, is well known. During this cycle, the relative composition of cattle numbers changes. Neumann describes this rather complicated sequence clearly.

> (The cycle) begins with an increased demand for breeding stock to expand herds. Prices of breeding stock soar, making the producing, or cow-calf enterprise, especially profitable. Cows, yearling heifers, and heifer calves are retained, while larger numbers of steers make up total cattle slaughter. Later, when calves from enlarged breeding herds reach maturity, total slaughter increases and prices break, often severely. Declines are sharpest

> for breeding stock and least for high-grade fed cattle. Thus the producing enterprise becomes relatively unprofitable, more cows are slaughtered, and there is a rush to expand the feeding business, using now the cheaper calves and yearlings. As the slaughter of cows and calves increases, cow herds are reduced and the calf crop becomes smaller. Eventually, total slaughter decreases and prices turn upwards, initiating a new cycle.
>
> (p. 27)

The existence of this cycle is known to producers, and it seems reasonable that they would temper their price expectations according to position in the cycle. What is not clear is how this information is incorporated, so empirical modeling is complicated. Ospina and Shumway attempt to capture the effect of cycle through the use of a polynomial specification for price expectations, although, empirically, this approach was not very fruitful.

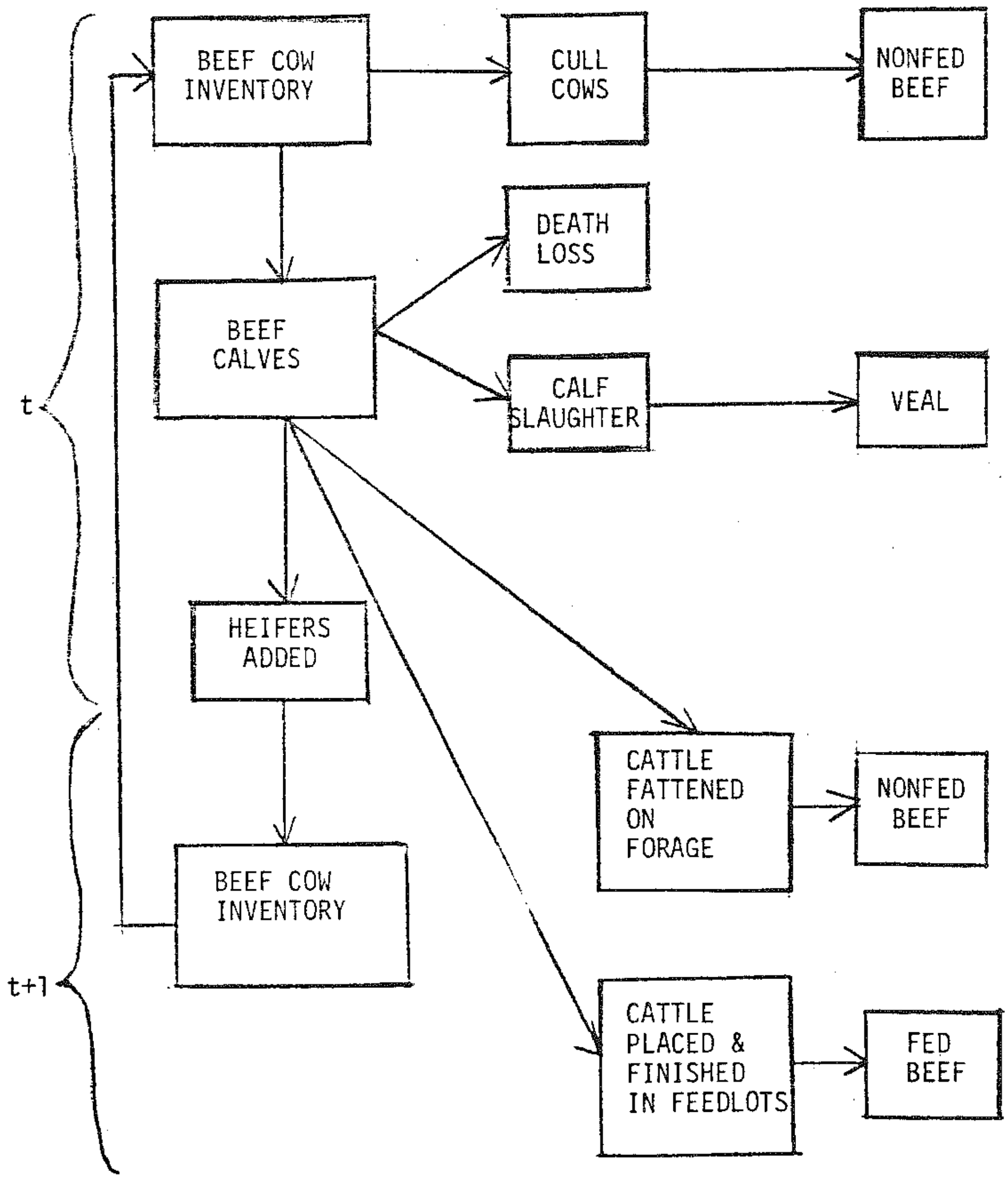
Although the influence of cyclical position on beef producers' price expectations is intuitively reasonable, it is not at all clear what measure might be included to capture this influence. However, it should not be ignored altogether. The current model incorporates it through the use of slope dummies on crucial production relations which vary markedly with position in the cycle, notably between the buildup and liquidation phases. These relationships include those between the calf crop and breeding inventory (smaller proportion of cows in breeding herd calving during liquidation than buildup), heifers added and the breeding inventory (smaller proportion of inventory replaced or added during liquidation), cow slaughter and breeding herd inventory (larger fraction culled during liquidation), and fed beef slaughter and the available feeder cattle supply (larger proportion of feeder cattle supply finished as fed beef during liquidation).

The use of dummies arbitrarily imposes the cyclical influence on production decisions by differentiating intracycle behavior. This approach is defensible because the timing of the cycles is known with relative certainty and the coefficients themselves are estimated, not imposed, on the model. In the examination of the empirical results, it will be seen that these postulated cyclical differences appear statistically significant and improve the explanatory power of the model.

One final point to be made about the specification of the beef submodel (and this is true for hogs and broilers, as well) is the use of real prices, either deflated by a producer price index or in ratio form. While other models may incorporate ratio variables ("to conserve degrees of freedom," according to Ospina and Shumway, p. 49), nominal prices predominate in the structural equations.

Figure 5 depicts the physical production process in the beef sector. This structure can be used to explain economic relationships and price determination in the market as in the structural equations given below. The cow-calf producer makes decisions based on the price of feeder cattle, one to two

Figure 5 Beef cattle production process



Adapted from Bain, p. 63

year old beef calves, which constitute his output and are sold to feedlots. This decision is made operational when he adds heifers to and culls cows from the breeding herd. However, as many as three years may elapse between the time he decides to increase production by adding a heifer and the time her progeny is ready for the feedlot. Consequently, he must make a decision based on his assessment of the price which will prevail when he enters the market a few years hence. In the empirical model, this price expectation is represented by current feeder cattle price. This price, in turn, is determined in feedlot operators' bidding for the fixed annual supply of feeder cattle. The operators' willingness to pay depends upon their assessment of the profitability of feeding cattle, represented in the model by the fed beef/corn price ratio. The feedlot operator, however, does not know fed beef price with certainty; because annual supply of fed beef is fixed within some maximum limit, this price is determined at the wholesale level of consumer demand. So, he must rely on expectations to guide his decisions; in the model, lagged fed beef price is taken as the expected price.

Not all feeder cattle go to feedlots, however. Before reaching the feedlot age, some are slaughtered as calves for veal or die or are added to the breeding herd. When older, those that remain can be sold to feedlots, or, if feeder cattle price is low (usually because corn price is high), they can be fattened on forage and sold by the cow-calf producer as nonfed beef. So, a high corn price may cause the diversion of some steers and heifers from feedlots, but it also affects those cattle that are placed on feed. They will enter the feedlots at lighter weights and will not be finished at weights as high as if the price of corn were lower. Thus, corn price affects total beef production through the slaughter mix of fed and nonfed beef and through the final weight of the feedlot animal. Nonfed beef is generally of lower quality than fed beef and comes from either cattle which are not placed on feed or from cull cows. It is a product distinct from fed beef and is treated as such.

The beef cattle production process is modeled in a series of 12 equations. The empirical results are presented below, along with an explanation of the equation's role in representing the steps in the process, as embodied in Figure 5.

Inventory of the breeding herd on January 1 depends on the additions and subtractions made to it during the year. Current inventory (BFCOWINV) is thus equal to last year's (BFCOWINV(-1)), plus the number of heifers added since then (HFADD(-1)), minus the number of cows culled (COWSLUS(-1)). This is rewritten as (12) below.

(12) 0 == BFCOWINV - BFCOWINV(-1) - HFADD(-1) + COWSLUS(-1)

The annual calf crop (CLFCROP) is determined by the size of the breeding herd (BFCOWINV) and also by the proportion of mature females within it.

(13) CLFCROP = 3.460 + 0.856 * BFCOWINV - 0.047 *DLIQ * BFCOWINV

(3.760) (0.078) (0.009)

RHO = 0.81 GLS

The dummy variable (DLIQ) takes on a value of one for the years 1974/75 through 1978/79, which represent the liquidation phase of the most recent beef cycle. The negative value of its coefficient implies that a smaller proportion of the breeding herd is bred during downswings than during upswings, so calf crops decline. This represents producers' plans to decrease future output by reducing the breeding herd. Cow's present value as consumption goods exceeds that as capital goods, so they are culled.

In the same year, decisions about breeding herd size are implemented through the addition of heifers (HFADD) and the slaughter of cows (COWSLUS). A certain amount of exchange goes on each year simply because some cows reach the end of their useful reproductive life and are culled. The net addition or subtraction determines the changes in output. The number of heifers added is expected to be a positive function of the size of the breeding herd (BFCOWINV) (reflecting normal replacement needs) and a positive function of the feeder cattle price (FCPKCUS) deflated by a producers' price index (PPIUS). This price response reflects producers' judgement about the value of a feeder steer two or three years hence, when a heifer's new progeny will be ready for the feedlot. While its coefficient's standard error is rather large, the variable's inclusion improves the turning point accuracy of the equation.

$$
\begin{aligned}
(14)\quad \mathrm{HFADD} = \ & \underset{(2.153)}{-11.585} + \underset{(0.039)}{0.361} * \mathrm{BFCOWINV} - \underset{(0.005)}{0.019} * \mathrm{DLIQ} * \mathrm{BFCOWINV} \\
& + \underset{(8.506)}{6.196} * \mathrm{FCPKCUS/PPIUS} \\
& \bar{R}^2 = 0.84 \qquad \mathrm{DW} = 1.61 \qquad \mathrm{OLS}
\end{aligned}
$$

The supply of feeder cattle in the next year (NETCROP) depends on the number of calves surviving from the original crop (CLFCROP(-1)). Some are slaughtered for veal (CLFSLUS(-1)), usually less than ten percent. Other die because of disease or inclimate weather (CLFDLOSS(-1)), about another ten percent. The ranks are also depleted by heifers removed to the breeding herd (HFADD(-1)). The remaining yearlings, about three-fourths of them steers, are candidates for placement in feedlots or grass-finishing. This relationship is written below.

(15) NETCROP == CLFCROP(-1) - CLFSLUS (-1) - CLFDLOSS(-1) - HFADD(-1)

This identity and that for the inventory (12) are included to ensure that the biological constraints on production are reflected in the supply of cattle. The purpose is to avoid overestimating supply response in a given period.

Cow slaughter (COWSLUS), an instrument of inventory adjustment, depends on the size of the breeding herd (again a reflection of normal replacement needs) and the real price of feeder cattle (FCPKCUS/PPIUS).

$$\text{(16)} \quad \text{COWSLUS} = \underset{(3.051)}{-3.114} - \underset{(12.057)}{35.490} * \text{FCPKCUS/PPIUS} + \underset{(0.055)}{0.234} * \text{BFCOWINV} + \underset{(0.007)}{0.038} * \text{DLIQ} * \text{BFCOWINV}$$

$\bar{R}^2 = 0.090$ DW = 1.27 OLS

When the real price of feeder cattle, representing producers' expectations of future prices, increases, cow slaughter declines because the value of future calves has increased. Cows are now more valuable as capital (production) goods than as consumption (slaughter) goods. The rate of cull which depends on age is reflected in the coefficient on BFCOWINV. The dummy DLIQ's coefficient indicates that more culling takes place during periods of liquidation than buildup, as producers reduce the size of the herd. Cows are a source of non-fed beef, which explains why hamburger is more plentiful, in the absolute and relative to other cuts, in the latter stages of a cycle.

Given a fixed annual supply of feeder cattle (NETCROP), feedlot operators bid on the animals based on their estimation of the profitability of feeding them. This expectation is represented by the ratio of expected fed steer price (FBCPUS(-1)) to corn price (COPFUSDT), which reflects the size of the feeding margin. Fed beef price is lagged because producers do not yet know with certainty what the price of their output will be. Feeder cattle price (FCPKCUS) deflated by the index PPIUS, is thus determined by feedlot operators' bidding. The bigger the price ratio (FBCPUS(-1)/COPFUSDT), the more profitable feeding is expected to be, and the more competitive and higher is the bidding for the available supply of feeder cattle. Feeder cattle price is then positively related to feedlot profitability.

$$\text{(17)} \quad \text{FCPKCUS/PPIUS} = \underset{(0.009)}{0.010} + \underset{(0.017)}{0.114} * \text{FBCPUS(-1)/COPFUSDT} + \underset{(0.006)}{0.025} * \text{D72}$$

$\bar{R}^2 = 0.70$ DW = 1.62 OLS

The dummy variable D72 is included for 1972/73 because price was unusually high. The consumer meat boycott and price controls in 1973 caused producers to hold cattle off the market during the spring and summer months. Slaughter was low as herd expansion continued.

The available feeder cattle supply is apportioned between feedlots and ranch-fed finishing. The size of the portion that is fed is represented here by slaughter numbers (FBSLUS) and is positively related to the expected profitability of feeding again represented by FBCPUS(-1)/COPFUSDT. The fed beef numbers are also a function of the size of the available feeder cattle supply (NETCROP).

(18) $FBSLUS = \underset{(5.819)}{-10.828} + \underset{(5.962)}{18.678} * FBCPUS(-1)/COPFUSDT + \underset{(0.164)}{0.780} * NETCROP$

$+\underset{(0.041)}{0.107} * DLIQ * NETCROP$

$\bar{R}^2 = 0.66 \quad DW = 1.51 \quad OLS$

The intracycle dummy DLIQ is included. Its coefficient implies that a greater proportion of the available feeder cattle supply are finished as fed rather than nonfed beef during the liquidation than buildup phase of the cycle. At this time, feeder cattle price will be at its cyclical low due to large supplies, enhancing profitable feeding opportunities.

At the same time, some part of the available feeder cattle supply will bypass feedlots and be finished on pasture. The lower the real price of feeder cattle (FCPKCUS/PPIUS) the fewer cattle go to feedlots. The cow-calf producer may decide to fatten the cattle himself rather than accept low prices from feedlot operators.

(19) $NFBSLUS = \underset{(1.250)}{13.108} - \underset{(14.150)}{90.563} * FCPKCUS/PPIUS + \underset{(0.538)}{1.553} * D74$

$RHO = 0.78 \quad GLS$

The dummy variable for 1974/75, D74, is included to capture the effects of the sharp increase in corn price which depressed feeder cattle price, already low with the cycle peaking and cattle supplies plentiful.

For those animals which do go to feedlots, the amount of weight gain will depend upon the profitability of feeding (FBCPUS(-1)/COPFUSDT). The more profitable is feeding, the higher the feeder cattle price and the higher the weights at which they move to feedlots and are subsequently finished. In this relationship, average feeder cattle liveweight (FCAVLWT) is a positive function of FBCPUS(-1)/COPFUSDT.

(20) $FCAVLWT = \underset{(0.166)}{6.147} + \underset{(0.309)}{2.152} * FBCPUS(-1)/COPFUSDT + \underset{(0.100)}{0.102} * D68$

$-\underset{(0.119)}{0.297} * D71$

$\bar{R}^2 = 0.78 \quad DW = 1.51 \quad OLS$

Identities convert livestock numbers and weights to production variables. Fed beef average liveweight (FBAVLWT) is determined in (21) as one and one half times the average feeder cattle weight (FCAVLWT) (an historically verifiable relationship). Multiplication by 100 converts poundage to a compatible scale.

In (22), fed beef production (FBPRDUS) is the product of the number of head of fed beef slaughtered (FBSLUS) multiplied by the average liveweight (FBAVLWT) and then by the 20-year average dressing yield (0.62) to get carcass weight.

(21) FBAVLWT == FCAVLWT / 0.66 * 100

(22) FBPRDUS == FBSLUS * FBAVLWT * 0.62

Nonfed beef production (NFBPRDUS), on the other hand, is the product of nonfed slaughter (consisting of nonfed steers and heifers (NFBSLUS) plus cull cows (COWSLUS)) and the average nonfed beef average dressed (carcass) weight (NFBAVDWT), which is exogenous.

(23) NFBPRDUS == (NFBSLUS & COWSLUS) * NFBAVDWT

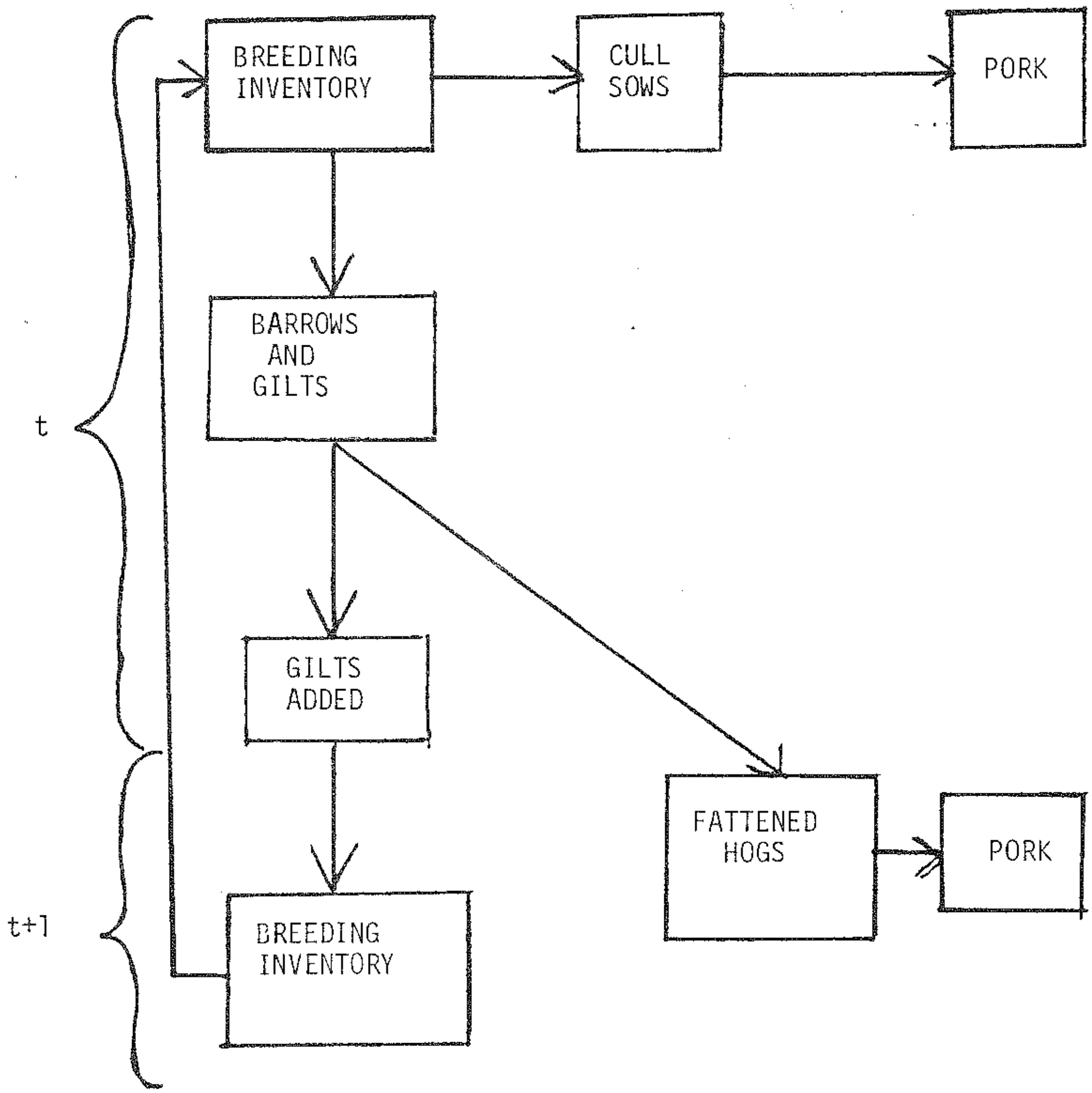
At the sample means, the calculated elasticity for fed beef slaughter with respect to expected fed beef price is 0.4 and for nonfed slaughter with respect to feeder cattle price it is -1.0. These values are expected since, within the year, little change can be made in fed slaughter due to feedlot capacities, while the greater elasticity of nonfed slaughter reflects the alternative production possibility of selling to feedlots.

Pork supply

The domestic hog sector, along with beef cattle, is a major consumer of US corn. Conceptually, problems of model specification here are quite similar to those already raised in the discussion of the beef sector. The structural equations which explain hog production resemble those which describe beef production. Figure 6 depicts the steps in hog production represented in the model. The basic difference lies in the length of the production cycle. Due to a nine month gestation period for cows, only one calf crop per year can be achieved. In contrast, given sows' gestation period of four months, it is common for the larger hog operations to turn out two pig crops per year. A sow can produce two litters of an average seven pigs each per year. To reflect this possibility, hog production is modeled in a semiannual time frame, breaking the year into two periods, December to May and June to November. (This breakdown was selected primarily because USDA data are available in this form.) The same set of structural equations were estimated over each time period, linked by an identity adding up breeding inventory changes.

Supply response in the hog sector, then, occurs within a six month period based on expected barrow and gilt and corn price. Breeding inventory changes are manifested in gilts added and sows slaughtered. Current slaughter depends on the size of the pig crop in the previous period as well as inventory adjustment (hogs, like cattle, can be viewed as both capital and consumption goods). The pig crop is determined by the numbers of sows farrowing, which in turn is a function of the size of the breeding inventory.

Figure 6 Hog production process



Empirical evidence points toward a 3.4 to 4 year hog cycle (Spreen and Shonkwiler, p. 1). A cycle closer to three years provides support for a lack of intracycle seasonality, implying four consecutive ten month breeding to slaughter stages (40 months or 3.33 years). As with beef, producers might reasonably be expected to consider cyclical position in formulating their price expectations. However, the attempt to identify differential impacts during buildup and liquidation phases using dummy variables, as with beef, produced no clearcut results. Consequently, the cycle is not explicitly imposed on the model, save for certain years in which the liquidation phase was drawing to a close. Two such years for both periods in which sows farrowing were a markedly lower proportion of the breeding inventory were 1968 and 1974, both of which occurred near the end of liquidation phases. June to November sow slaughter as a proportion of breeding inventory also fell in these years. An unusual number of gilts were added in 1969 at the start of a buildup phase.

The estimated empirical equations which describe the hog production process are given below, along with the same summary statistics as before. As in the beef submodel, the breeding herd inventory is a function of net addition and subtraction over the previous period. The expression is written in terms of June 1 inventory (HGBINV2), equal to the previous year's June 1 inventory (HGBINV2(-1)) and the previous six month's sow slaughter (SOWSLUS1 over December to May), plus gilts added in the past year, i.e., previous year June to November (GADD2(-1)) and previous six month's (December to May) (GADD1). This identity thus ensures that all changes add up over the course of the year.

The next step in the process is to determine the number of sows farrowing in the breeding herd. There are no comparable statistics, such as cows bred for cattle. Sows farrowing are included because it improves the accuracy of prediction of the pig crop, rather than basing it on the size of the breeding herd which includes immature females. The number of sows farrowing over the period December to May (SOWFAR1) is a positive function of the December 1 breeding inventory (HGBINV2(-1) - SOWSLUS2(-1) - GADD2(-1)). The dummy for 1968/69 and 1974/75 (D6874), whose inclusion is justified above, has a negative coefficient, indicating that fewer sows in the herd farrowed during these severe liquidation periods.

$$(25)\quad \text{SOWFAR1} = \underset{(0.005)}{0.744} * (\text{HGBINV2}(-1) - \text{SOWSLUS2}(-1) - \text{GADD2}(-1))$$

$$- \underset{(0.014)}{0.075} * \text{D6874} * (\text{HGBINV2}(-1) - \text{SOWSLUS2}(-1) - \text{GADD2}(-1))$$

RHO = 0.98   GLS

Similarly, sows farrowing during June to November (SOWFAR2) is a function of the June 1 breeding inventory and the same dummy as above.

$$(26)\quad \text{SOWFAR2} - \underset{(0.020)}{0.666} * \text{HGBINV2} - \underset{(0.138)}{0.012} * \text{D6874} * \text{HGBINV2}$$

RHO = 0.79 GLS

The pig crop (about seven per litter) produced by sows appears in the next six month period. The December to May pig crop (PCROP1) depends on the number of sows farrowed the previous June to November (SOWFAR2(-1)). The second half pig crop (PCROP2) likewise depends on sow numbers the previous December to May (SOWFAR1).

(27) PCROP1 = 7.167 * SOWFAR2(-1)
(0.062)

RHO = 0.71 GLS

(28) PCROP2 = 7.187 * SOWFAR1
(0.045)

RHO = 0.78 GLS

The pig crop is ready to be marketed in the next six month period, after being fattened. The recursivity continues so that barrow and gilt slaughter over the period December to May (BGSLUS1) is a function of the previous period's pig crop (PCROP2(-1)), slaughter over June to November (BGSLUS2) a function of the December to May pig crop (PCROP1). These are not identities because of the possible overlap between periods.

(29) BGSLUS1 = -1.822 + 0.852 * PCROP2(-1)
(3.073) (0.068)

RHO = 0.80 GLS

(30) BGSLUS2 = -0.193 + 0.709 * PCROP1
(0.266) (0.090)

RHO = 0.98 GLS

As in the beef sector, inventory adjustment is accomplished through the addition of new stock as gilts (GADD) and culling of sows (SOWSLUS). Many hog producers also raise corn and so have the option to sell grain directly when corn price is high or to convert it into pork when its price is low. The relative prices of hogs and corn are the basis for the farmer's production decision. Last period's price is the expected hog price, while current corn price is the expected grain price since at least the size of the crop is known when decisions are made.

Sow slaughter depends on the size of the breeding herd and expected hog and corn price which represent the value of sows' future offspring. December to May sow slaughter (SOWSLUS2) is a positive function of the December 1 breeding inventory (HGBINV2(-1) - SOWSLUS2(-1) + GADD2(-1)). It decreases with an increase in expected real hog price (value of pigs up (BGPFUS2(-1)/PPIUS) and increases with an increase in expected real corn price (COPFUSDT/PPIUS). The same relationships hold among second period variables.

(31) $$\mathrm{SOWSLUS1} = \underset{(0.749)}{0.138} - \underset{(0.069)}{0.223} * (\mathrm{GHBINV2}(-1) - \mathrm{SOWSLUS2}(-1) + \mathrm{GADD2}(-1))$$

$$-\underset{(5.516)}{11.812} * \mathrm{BGPFUS2}(-1)/\mathrm{PPIUS} + \underset{(2.086)}{5.531} * \mathrm{COPFUSDT}/\mathrm{PPIUS}$$

$$- \underset{(0.220)}{0.294} * \mathrm{D75}$$

$$\bar{R}^2 = 0.63 \qquad \mathrm{DW} = 1.28 \qquad \mathrm{OLS}$$

The 1975-76 dummy (D75) is included in (31) to account for a 20 percent drop in sow slaughter during December 1975 to May 1976 over the previous period, June to November of 1975 (recall the corn crop year runs from October 1 to September 30). This drop occurred despite an extraordinarily high corn price and may be attributable to farmers' decisions to begin expansion after the 1973/74 peak and subsequent liquidation. While the standard error of the coefficient is relatively large, the inclusion of the variable improves the equation's turning point accuracy.

(32) $$\mathrm{SOWSLUS2} = -\underset{(1.567)}{0.707} + \underset{(0.118)}{0.375} * \mathrm{HGBINV2} - \underset{(0.018)}{0.058} * \mathrm{D6874} * \mathrm{HGINV2}$$

$$-\underset{(8.07)}{12.824} * \mathrm{BGPFUS1}/\mathrm{PPIUS} + \underset{(3.792)}{6.747} * \mathrm{COPFUSDT}/\mathrm{PPIUS}$$

$$\bar{R}^2 = 0.68 \qquad \mathrm{DW} = 1.75 \qquad \mathrm{OLS}$$

In (32), the dummy reflects the decrease in sow slaughter in the second half of the 1968/69 and 1974/75 crop years. In both cases, the current and immediately preceding six months had unusually low farrowing rates (see (26)). The subsequent sow slaughter decline may be interpreted as the start of the cycle's expansion phase.

The number of gilts added (GADD) within a period is postulated to be a positive function of sow slaughter (SOWSLUS) that period (to reflect normal replacement rates). The number added should respond positively to an increase in the expected real hog price (BGPFUS/PPIUS) and negatively to an increase in real corn price (COPFUSDT/PPIUS).

(33) $$\mathrm{GADD1} = \underset{(0.754)}{2.207} + \underset{(0.245)}{0.233} * \mathrm{SOWSLUS1} + \underset{(7.667)}{8.510} * \mathrm{BGPFUS2}(-1)/\mathrm{PPIUS}$$

$$-\underset{(2.728)}{6.610} * \mathrm{COPFUSDT}/\mathrm{PPIUS} + \underset{(0.231)}{0.910} * \mathrm{D69}$$

$$\bar{R}^2 = 0.58 \qquad \mathrm{DW} = 1.83 \qquad \mathrm{OLS}$$

$$(34)\quad GADD2 = \underset{(1.026)}{0.496} + \underset{(0.190)}{0.512} * SOWSLUS2 - \underset{(0.064)}{0.334} * D6975 * SOWSLUS2$$

$$+ \underset{(10.878)}{14.558} * BGPFUS1/PPIUS + \underset{(3.692)}{0.499} * COPFUSDT/PPIUS$$

$$\bar{R}^2 = 0.65 \qquad DW = 2.40 \qquad OLS$$

In (34), the coefficient on expected corn price (COPFUSDT/PPIUS) has a positive instead of a negative sign and an extremely large standard error. Although the sign on expected hog price (BGPFUS1/PPIUS) is positive, as presumed, its coefficient, too, has a large standard error. These poor results for the price variables may indicate that most inventory adjustment takes place in the first period, when a good estimate of corn price can first be made. In the simulation these price variables were dropped.

The elasticity of hog supply response (as manifested in inventory adjustment decisions) is approximately the same with respect to a change in corn price as with respect to a change in barrow and gilt price. In the empirical specification, the hog/corn price ratio was not a significant variable, even though the ratio form imposes identical elasticities with respect to each price. The index-deflated specification was more satisfactory, although in some cases, these variables had large standard errors. They were retained, however, because in most cases the signs were correct. At the sample means, calculated elasticities for gilts added in both periods with respect to own price were about 0.3. With respect to corn price, the value for December to May gilts added was -0.3. In both periods, sow slaughter elasticities with respect to barrow and gilt and corn price were approximately -0.3 and 0.3, respectively. The similarity in marginal response between the two periods could be taken as evidence that temporal disaggregation was not warranted, but the cyclical fluctuation in numbers still justifies the separation. In general, the temporally disaggregated equations were superior to those estimated on an annual basis, both in terms of goodness-of-fit and coefficient signs.

Broiler supply

Since World War II, growth in per capita consumption of broilers has doubled and redoubled. Per capita consumption in 1980 was 50 pounds, compared with 28 pounds in 1960. At the same time, consumption of turkey has increased only four pounds per capita, to ten in 1980. Similarly, egg consumption fell from 334 per person in 1960 to 272 in 1980. This rapid expansion in the broiler industry has occurred with its separation from other pountry processes and significant changes in industrial structure and technological procedures.

Rapid structural and technical change, coupled with a relatively short production cycle, complicate attempts to model broiler output over the past 20 years in an annual framework. "Biological advances relating to broiler to broiler production, along with simultaneous improvements in flock housing and care, resulted in a nearly 50 percent decrease in feed consumed per 100 pounds of output between 1945 and 1972" (Reimund, Martin, and Moore, p. 7). Consequently, broiler production (BRPRDUS) is modeled rather simply, output dependent on the broiler/corn price ratio (POPFMUS/COPFUSDT) and a linear time trend (TIME) included to capture the effects of structural and technical change. The estimated equation is given below.

$$(35)\quad \text{BRPRDUS} = \underset{(1.050)}{4.184} + \underset{(2.901)}{5.270} * \text{POPFMUS/COPFUSDT} + \underset{(0.027)}{0.448} * \text{TIME}$$

$$\bar{R}^2 = 0.95 \qquad DW = 1.30 \qquad \text{OLS}$$

These results imply a price elasticity of broiler supply with respect to own and corn price of positive and negative 0.15, respectively, at sample means.

Derived Feed Corn Demand

Aggregate demand for feed corn arises from derived demands in the various livestock sectors, in which feed needs are closely related to production levels. Due to economic, technical, and biological differences, sectors have varying corn requirements per unit of output. Aggregate feed demand equations cannot reflect these intersectoral differences which may affect elasticities of demand with respect to corn price. Moreover, aggregate equations cannot capture short run production changes due to differences in ration flexibility nor the change in the overall mix of livestock numbers in the longer run, as composition changes in response to cyclical factors. To capture price adjustment in these markets, all these possibilities must be reflected in the empirical model.

Richardson and Ray present the most comprehensive framework for evaluating demand for feedgrains and concentrates by livestock category. As to the advantage of such a disaggregated approach, they state,

> Using feed demand parameters by livestock category enables analysts to evaluate policy effects of changes in feed demand quantities and feed costs within the livestock economy as well as to provide more reliable estimates of total changes in feed demand quantities.
>
> (p. 29)

They construct a system of four equations to be applied to each livestock sector which explain total concentrates and proportion of concentrates which are feedgrains (all in terms of corn equivalent feed units). For any category, the demand for total concentrates is equal to "the level of livestock production multiplied by the average concentrates feed conversion rate," where this rate is postulated to be a function of corn price, livestock price, and a time trend (p. 24). Feedgrain demand is then equal to the total concentrates demanded multiplied by the estimated percentage of feedgrains in total concentrates fed, this fraction an estimated function of feedgrain price, livestock price, price of by-product feeds, a time trend and an error term (p. 25).

The current study does not incorporate the full system with the neoclassical, derived demand equations; it necessarily makes some simplifying assumptions, but the specification still provides a good representation of differential derived corn feed demand.

The first simplification is the maintained assumption that the percentage of total concentrates fed which are feedgrains (and, more specifically, corn) is constant over time. Both in the aggregate and by livestock sector, this assumption is fairly well justified. In terms of corn feed equivalent, corn has averaged, with no discernible trend, 55 percent of all concentrates fed over the period 1960 to 1978, with a standard deviation of 3.6 percentage points. For cattle on feed, the average percentage has been 55 percent (standard deviation of 4.6), for broilers 55 percent (standard deviation of 4.0), and for hogs 73 percent (standard deviation of 2.5). The most notable variation occurs in years (such as 1970) in which corn price was very high, when corn share does fall. While this movement does suggest some sensitivity of the corn share to feed and livestock prices, there was judged to be sufficient stability to warrant the assumption of constancy.

Having assumed that a change in feed demand for corn does not result from a change in concentrate ration composition, it is possible to narrow the investigation to changes which arise due to fluctuation in livestock production and thus total concentrate demand. Consequently, the demand for corn by any livestock sector will be equal to the level of production multiplied by a corn conversion or requirement rate per unit of output. Output can be measured either in terms of total weight or in animal slaughter numbers; the choice, as is discussed more fully below, is dependent on technical and biological characteristics peculiar to each sector. The determination of the proper output variable specification and relevant conversion rate for each of the beef, hog, broiler, and dairy sectors is discussed below, with reference to the temporal as well as biological differences in derived demand response across livestock types.

In the case of beef cattle, derived corn demand is postulated to be a stochastic function of fed beef production in pounds of finished liveweight. Recall from the earlier description of the beef sector that fed beef production is calculated as the product of the number of head of fed beef cattle slaughtered and the average finished liveweight in any given year. Corn price influenced beef output through both the mix of fed versus nonfed cattle slaughter and finished liveweight. So, by using the total weight production specification, both of these short run influences can be incorporated. In the longer run, the number of cattle slaughtered will reflect cyclical movement in the sector and thus be translated into an effect on its corn demand.

The determination of an appropriate conversion or corn requirement rate is most complex; it is estimated in the model as the coefficient on the beef production variable due to this difficulty. The various influences represented in this value are now discussed. Historically, the amount (in pounds) of corn required per pound of fed beef production has climbed from 1.66 in 1960, to 1.99 in 1965, to 2.28 in 1970, to 2.81 in 1978. This increase has coincided with the advent of large, intensive feedlot operations and a change in the quality of fed beef, reflected in the marbling characteristic of fat, corn fed and feedlot finished beef. The change in the type of fed beef produced explains much of the increased use of corn since average finished liveweights have been around 1,100 pounds, with no discernible trend, and standard deviation of 30 pounds, which is about three percent of mean weight. Over this same period, the dressing yield of live to carcass weight has been more or less constant, so, again, the net effect of increased corn requirement has been a quality change and not a quantity increase. Furthermore, there is evidence that liveweights also move cyclically, being highest during the liquidation phase when feeder cattle are relatively cheap and there is more to be made on the feeding margin.

In addition to these changes in the nature of the production process, the empirical estimate of the corn requirement rate is influenced by the specification of the dependent variable, corn fed to beef (CBEEFUS). Here, all corn is assumed consumed by cattle on feed, when in fact usually about 15 percent of the total goes to other beef cattle (the fraction fluctuates somewhat with position in the cycle as it affects culling rates). The consequence of this is that the estimated coefficient on fed beef production also reflects this stable component of usage by other beef; the inclusion of a separate variable for nonfed beef production introduced significant problems of multicollinearity with the fed beef variable.

While it would have been possible to introduce the calculated requirement rate exogenously, this approach was not taken since the annual rate is influenced by stochastic events arising from disturbances in the corn market as well as in livestock product demand. Moreover, for the purposes of extrapolation, the estimation of a coefficient which reflects a (lower than current actual) mean rate is preferable given the present trend away from marbled to leaner beef. This quality change may imply a drop in the amount of corn required per pound of fed beef production. The estimated equation for corn fed to beef cattle (CBEEFUS) is given below.

$$\text{(36)}\quad \underset{(9.033)}{\text{CBEEFUS} = -6.459} + \underset{(0.0005)}{0.002} * \text{FBPRDUS} + \underset{(2.458)}{9.498} * \text{D72} + \underset{(2.505)}{11.953} * \text{D73}$$

$$\text{RHO} = 0.89 \qquad \text{GLS}$$

The D72 and D73 dummy variables for the crop years 1972/73 and 1973/74 represent unusually high corn fed levels (around 40 MMT versus 35 MMT in 1971/72 and 23 MMT in 1974/75). This phenomenon is explained by high beef prices during the latter part of a period of contracted feeder cattle supply while large herds were being built up and the beginning of the liquidation phase in late 1973, continuing to the next year. Note that the coefficient on fed beef production (FBPRDUS) has no direct interpretation in physical terms as production units are million pounds while corn use units are million metric tons.

The elasticity of corn use with respect to fed beef production is 1.36 at the sample means. Richardson and Ray argue that its true value is unity since "a given percentage change in livestock output should result in the same percentage change in feedgrains demanded - everything else including prices and feeding efficiency held constant" (p. 24). The greater than unitary elasticity here is explained by both the historic inconstancy of feeding efficiency and prices, as described above. The Richardson and Ray proposition assumes constant marginal product over all levels of output, which seems unlikely for biological reasons. Beyond a certain weight, more and more corn must be fed to yield another unit of beef (Lasley, p. 342). In support of this idea, Ahalt and Egbert found the aggregate elasticity of feed consumption with respect to livestock production to be 1.28 (p. 45).

In contrast to that of the beef cattle sector, the hog demand for corn is described as a nonstochastic function of the number of head of hogs slaughtered multiplied by the average annual amount of corn fed per head, where this rate enters as an exogenous vector. The slaughter numbers are those predicted endogenously by the model taking into account relative corn and hog prices. The underlying conditions and the nature of change in the hog production process has not been the same as that in beef, which explains the differences in the demand specification. These factors are examined more closely.

Over the past twenty years, hog liveweights have averaged about 240 pounds, with a standard deviation of only about two pounds, less than one percent of mean weight. However, over the same period, dressing yields have increased dramatically, a cumulative ten percent from 1960 (when average dressed weight was 146 pounds from a 238 pound live hog) to 1980 (when a 242 pound hog dressed out at 172 pounds). Consequently, if the pork production variable were specified in terms of total liveweight, the increase in conversion efficiency would be obscured. Production is therefore expressed in terms of slaughter numbers, which are subsequently multiplied by the annual average dressed weight (an exogenous vector) to yield production in terms of carcass weight (see (8) and (9)). Since hog farmers have very little opportunity for varying corn use and thus weights in the short run, the slaughter number variables adequately capture the magnitude of production derived demand.

At the same time that meat yield per animal has been increasing, with constant liveweight, corn consumed per animal has been decreasing, introducing another source of gain in productive efficiency. In 1960, 0.53 MT (about 1200 pounds) of corn were fed per head; by 1979, the figure was 0.44 MT (about 970 pounds). This general downward trend has some cyclical elements and is punctuated in a few places by unusually low years, attributable to very high corn price (e.g., after the 1970 corn blight, when 0.38 MT, or 840 pounds, were fed per head). There is apparently little substitution of other feedgrains for corn in hog production; corn comprises 94 percent of all grains fed across all types of operations (feeder pig, farrow to finish, and feeder pig finishing) (Van Arsdall, p. 30). The concentration of hog production in the North Central corn belt states largely explains this rigidity, since, in most cases, feed corn is grown in support of the same farm's hog operation. For these reasons, the per hog corn requirement (CHOGAV) is entered as an exogenous vector of calculated historical values. The whole expression for corn demand is nonstochastic because of the restrictions on ration flexibility and output modification in the short run. The two relations, one for each six month period (CHOGSUS1 and CHOGSUS2) are given below, where BGSLUS and SOWSLUS are current barrow and gilt and sow slaughter, respectively.

(37) CHOGSUS1 == CHOGAV * (BGSLUS1 + SOWSLUS1)

(38) CHOGSUS2 == CHOGAV * (BGSLUS2 + SOWSLUS2)

Derived corn demand for broilers and other poultry is specified as a function of the corn/broiler price ratio and broiler production. The dependent variable includes not only broiler corn use but that of hens and pullets, chickens raised for replacement, and turkeys. The absolute amount of corn consumed by these other poultry types has changed very little over the past twenty years. Hens and pullets annually account for about 10 MMT, replacement chickens for 2 MMT, and turkeys for 2.5 MMT. The growth in corn use has come from the broiler sector, whose total use was 5 MMT in 1960 and 9 MMT by 1980. At the same time, broiler production per capita has doubled, largely due to improvements in economic and technical efficiency. The influence of these factors on the specification of the derived demand equation is now examined.

Since World War II, there have been dramatic developments in the broiler industry. In economic structure, there occurred a transformation from "an industry of small, widely scattered, and independent producers selling through an open market into one of the most highly concentrated, integrated and industrialized agricultural subsectors" (Reimund, Martin, and Moore, p. 3). The appearance of large scale operations enhanced feeding efficiency in distribution and nutrition. This change facilitated the most significant advance affecting feeding requirements, which were biological, in breeding meatier chickens with improved gain performance. These rapid structural and technical changes made modeling rather difficult, as discussed earlier.

The derived demand equation for corn fed to poultry (CPOLTUS) is given below.

(39) CPOLTUS = 10.572 - 0.461 * COPFUSDT/POPFMUS + 0.706 * BRPRDUS

(1.610) (0.445) (0.115)

$\bar{R}^2 = 0.68$ DW = 1.12 OLS

In the equation, the corn/broiler price (COPFUSDT/POPFMUS) is included to capture the more adjustable nature of broiler output with several production cycles annually. Comparing these resutls to those of (35) which explain broiler production (BRPRDUS), the elasticity of broiler supply with respect to corn price is -0.15, while here, the elasticity of corn fed with respect to corn price is -0.09 (at sample means).

The broiler production variable functions as a proxy for all poultry production. It is difficult to think of a sensible index which could be used to aggregate broiler, egg, and turkey production; if all are entered separately, multicollinearity causes problems in coefficient estimation. Thus, this coefficient has no strict interpretation in a physical conversion sense.

Corn use by dairy cattle (CDAIRUS) is specified simply as a function of time trend (TIME) and appropriate dummies. The difficulty of modeling the dairy sector due to the degree of government involvement, which distorts free market price relationships in a complex way, has been previously noted. In addition, production efficiency gains have been significant, with the cow population falling by 12 percent while milk production rose 30 percent over the past fifteen years (Crittendon, p. F7). Moreover, corn use in the sector has been quite stable, as shown in the previous chapter.

$$\text{(40)} \quad \underset{(0.458)}{\text{CDAIRUS} = 10.398} + \underset{(0.039)}{0.326} * \text{TIME} - \underset{(0.884)}{2.657} * \text{D70} - \underset{(0.886)}{0.448} * \text{D71}$$

$$\bar{R}^2 = 0.81 \qquad DW = 1.23 \qquad OLS$$

The two dummy variables, D70 and D71, for 1970/71 and 1971/72, capture reduced usage (and proxy price response) during the year of the corn blight and recovery following (the dummy is included mainly to prevent turning point error).

Food, Seed, and Industrial Demand

As discussed in the previous chapter, food, seed and industrial demands together have been a relatively small and stable component of domestic corn disappearance. While separate equations could be specified for each category, in view of the historical stability the aggregated approach was deemed satisfactory. If, in the future, however, industrial demand for corn to manufacture high fructose syrup or ethanol becomes more important, these relationships would be more properly separated. As it is, the disappearance category (CFOODUS) is specified as a function of its own lagged value.

$$\text{(41)} \quad \text{CFOODUS} = \underset{(0.419)}{-0.493} + \underset{(0.041)}{0.989} * \text{CFOODUS(-1)}$$

$$\bar{R}^2 = 0.98 \qquad DW = 2.17 \qquad OLS$$

The implication here is zero price elasticity of demand, in the aggregate, for all three sectors.

Stock Demand

Stocks accumulate within a year as a result of commercial demand and of government demand manifested as a byproduct of agricultural support programs. As Womack discusses, commercial actors hold stocks for precautionary, speculative, and transactional needs (p. 24). The structural equation is derived based on assumptions about the relevant motivations on the part of market participants; explanatory variables may include price, lagged stocks, and lagged and/or current production. In his own commercial stock equation for corn, Womack has as explanatory variables corn price, corn production, and lagged government stocks, which, altogether, are meant to describe stocks amassed for all three of the motivations mentioned (p. 36). His specification is typical of those found elsewhere in the empirical literature.

Government stocks of corn have fluctuated markedly over the historical period, as the previous chapter noted. Their accumulation under past government support programs has largely been a function of the relationship between the loan rate and market price of corn, and, in the 1960s and early 1970s, the amount of corn area set aside. Although the motivations behind the accumulation of the two types are surely different, the level of commercial demand will be expected to depend at least partially on the size of government holdings as a measure of overall reserves. So, ideally, the structural model would incorporate two, interdependent stock demand equations, one explaining commercial inventories, the other those of the government.

Unlike any other grain stock accumulated under a support program, that of corn was drawn down to zero for four years during the tight markets of the mid-seventies, from 1973/74 to 1976/77. At the same time, private inventories were at all-time lows. While this is explainable in terms of the variables described above, empirical problems in estimation and simulation when observations of zero occur in the dependent variables made necessary the combination of the two stock categories into one. Consequently, only one total stock equation was estimated. It is given below.

$$\text{(42)}\quad \underset{}{\text{CSTKTUS}} = \underset{(7.844)}{-16.795} + \underset{(5.843)}{28.551} * \text{COPLDT/COPFUSDT} + \underset{(0.045)}{0.074} * \text{CPRDUS}$$

$$+ \underset{(0.142)}{0.342} * \text{CSTKTUS}(-1)$$

$$\bar{R}^2 = 0.83 \qquad DW = 2.12 \qquad \text{OLS}$$

Here, total stock accumulation (CSTKTUS) is positively related to the ratio of the loan rate to the market price (COPLDT/COPFUSDT); the higher the loan rate relative to the market price, the greater the stocks placed in storage in response to a softer market. Stocks are positively related to the size of current production (CPRDUS) and last year's (beginning) stocks (CSTKTUS(-1)), two quantities which measure availability and need, reflecting precautionary and transactional motivations on the part of commercial participants. At the sample means, the elasticity of corn stock demand with respect to the loan rate is 1.2 (-1.2 with respect to corn price). Womack's estimates implied inelastic price response for commercial stock demand alone, about -0.9 with respect to corn price (p. 68). The difference is explained by the inclusion of government stocks, which react more strongly to prices because of the support program mechanism.

In the future, the operation of the farmer owned reserve (FOR) may require some modification of the structural form of (42). Meyers and Ryan suggest that the FOR has created a fundamental change in grain markets, since the "FOR adds a price responsive component to the market and thus increases the elasticity of total market demand when the FOR is open for placements or redemptions" (p. 319). In that respect, the effect of the operation of the FOR on commercial stocks is more significant (so the two should be separated if possible) and some other price variable than the loan rate (perhaps one that measures storage subsidy) might be appropriate.

World Corn Import Demand

Earlier, the rationale for the aggregation of world corn importers was set forth. For convenience, these groups are listed below:

GROUP I (CIMPI) - Japan, South Korea, Taiwan, Malaysia, Mexico, Egypt, Israel;

GROUP II (CIMPII) - Eastern European bloc countries;

GROUP III (CIMPIII) - European Community (EC-9);

GROUP IV (CIMPIV) - Canada, Spain, Portugal, Greece.

The criteria on which the aggregation has been based included domestic feedgrain and livestock economies, income levels, and trade policies.

In general, the empirical results showed zero price elasticity of demand, with the exception of the Eastern European countries. This is not surprising considering the highly insulated nature of most of the markets. Livestock production and domestic coarse grain supply were of most importance in explaining imports. Overseas corn imports, then, are by and large explained by factors exogenous to the US corn market. This price inelasticity of demand compounds the instability the US faces as the residual supplier in the world market.

In (43) below, Group I's imports (CIMPI) are a positive function of their livestock production (measured in pounds of liveweight). These countries, in general, have little domestic grain production and rely heavily on the world market. Moreover, a steady supply of livestock products for domestic consumers is a priority, particularly in East Asia, so price considerations are secondary compared to stability and adequacy of supply.

$$\text{(43)} \quad CIMPI = \underset{(1.136)}{-3.735} + \underset{(0.407)}{4.499} * LVSTKI$$

$$RHO = 0.60 \qquad GLS$$

Eastern Europe's corn imports (CIMPII in (44) below) show some response to deflated world corn price (COPFUSDT, the US price, where WLDCPI is a world consumer price index). The implied elasticity is very low, -0.3 at the sample means. Although the price coefficient's standard error is rather large, the variable was retained as it helped the equation's turning point accuracy in the 1970s. Imports are inversely related to internal coarse grain production

(CGPRDII) and positively related to internal livestock production (LVSTKII), mostly pork and broilers, measured in liveweight.

(44) CIMPII = -2.369 - 0.050 * CGPRDII + 0.002 * LVSTKII
(2.158) (0.745) (0.0004)

-0.816 * COPFUSDT/WLDCPI
(1.065)

$\bar{R}^2$ = 0.80 DW = 1.31 OLS

The European Community's imports (CIMPIII) increase with increases in domestic livestock production (LVSTKIII). Unlike Eastern Europe, though, EC imports vary directly with internal coarse grain production (CGPRDIII); imports have usually accounted for about a quarter of all grains fed in the Community, indicating that they supplement rather than substitute for domestic production. The dummy for 1976/77 explains a very poor EC harvest and consequent usually large entry into the world market.

(45) CIMPIII = 1.017 + 0.424 * LVSTKIII + 0.154 * CGPRDIII + 6.741 * D76
(3.344) (0.319) (0.063) (0.991)

RHO = 0.66 GLS

The final group's behavior (CIMPIV in (46) below) has been so exceptionally stable that a linear time trend was used to describe it. Even major domestic import policy shifts would not likely appreciably affect world market conditions.

(46) CIMPIV = 0.162 + 0.392 * TIME
(0.429) (0.037)

$\bar{R}^2$ = 0.87 DW = 1.11 OLS

The description of the world market is completed by a market clearing identity, presented below. The construction of the identity sets the United States as a residual supplier (COUXTUS) to the world market, which follows from the conclusions reached after an examination of historical market behavior. The equation is also given at the end of this chapter with the rest of the identities.

(52) COUXTUS == CIMPI + CIMPII + CIMPSU + CIMPIII + CIMPIV + CIMPROW
- COUXTROW

On the demand side, the two exogenous factors are the Soviet Union's imports (CIMPSU) and the small market share of the rest of the world (CIMPROW).

While it is possible to estimate an equation to explain Soviet imports since 1972, it is not possible to find a specification that performs well over the entire historical period. In the 1960s, the Soviets were either not importers or net exporters of corn. Consequently, Soviet imports were entered exogenously, so the model in historical simulation reflects the influence of actual Soviet behavior rather than an approximation to it. On the supply side, the quantities exported by other countries (COUXTROW, which includes Argentina, South Africa, Thailand, and the rest of the world) also enter the model exogenously. The net effect of the five equation world market submodel is to place the burden of adjustment to changes in corn supply and price on the domestic US economy.

Domestic Corn Supply

Four equations explain domestic US corn production (CPRDUS): area planted (COAPLUS); area harvested (COAHGUS); yield (CYLDGUS); and an identity. The statistical results are given below followed by an explanation of the equations' specifications.

$$(47)\quad COAPLUS = \underset{(4.453)}{24.487} + \underset{(3.045)}{7.183} * COPFUSDT(-1)/SOYPUSDT(-1) + \underset{(0.095)}{0.136} * COAPLUS(-1) - \underset{(0.071)}{0.504} * COASAUST$$

RHO = 0.96 GLS

$$(48)\quad COAHGUS = \underset{(0.795)}{0.361} + \underset{(0.127)}{0.844} * COAPLUS$$

$\bar{R}^2 = 0.98$ DW = 1.84 OLS

$$(49)\quad CYLDGUS = \underset{(0.193)}{4.318} - \underset{(0.027)}{0.985} * PP7PZ + \underset{(0.021)}{0.191} * TIME - \underset{(0.261)}{0.979} * D70 - \underset{(0.305)}{0.524} * D74$$

$\bar{R}^2 = 0.90$ DW = 1.93 OLS

$$(50)\quad CPRDUS == COAHGUS * CYLDGUS$$

The acreage planted equation (47) incorporates the expected relative price of corn and soybeans (COPFUSDT(-1)/SOYPUSDT(-1)), area planted the year before (COAPLUS(-1)), and the area set aside under the diversion program (COASAUST). Ultimately, this final variable is a function of support and diversion payments' relation to the market price of corn, the factors which influence a farmer's decision to participate in such a government program. Furthermore, the set aside variable is a significant influence mostly in the 1960s and early 1970s; after 1972, there was very little corn area set aside, as diversion requirements were eliminated when markets tightened. In the latter part of the decade, then, the relative price of corn to soybeans, crops often grown in rotation, was perhaps the dominant influence. The estimated elasticity of response with respect to corn price is 0.12, at sample means. In comparison, Houck et al. found an elasticity of the same magnitude with respect to the price variable in their estimated area planted equation. Their variable, however, was constructed to incorporate the effective support rate (p. 20).

Area harvested is not usually the same as area planted due to failure which occurs even in normal years and also possibly due to discrepancies in data gathering. However, because corn production is equal to area harvested multiplied by yield per unit area, a transformation is required. In (48), area harvested (COAHGUS) is described as a stochastic function of that planted (COAPLUS) to recognize the unpredictable influence of weather on farmers' production plans. The formulation is also necessary in the case of corn because reported area planted is that for all purposes: grain; silage; and forage. Thus, the proportion of area harvested for grain is a function not only of weather but of the original planting pattern. The coefficient on area planted in (48) thus represents the historical average of the grain to all other uses ratio as well as the average failure rate, two influences which cannot be disentangled with the available data.

Yield is calculated on harvested area, so this quantity is influenced by weather events indirectly and also directly, since bad weather not only reduces the proportion of area harvested to that planted, but also the yield per acre. Again, however, the available data does not allow these effects to be identified separately. In (49), yield (CYLDGUS) is specified as a function of fertilizer price index (PP7PZ) representing the cost of a major input and a time trend (TIME) to capture general improvements in production practices and technology. The two dummies D70 and D74 account for two exceptionally poor years, due to blight in 1970 and drought in 1974.

Identities

Three identities close the model. They are given below.

(51) CLVSTKUS == CBEEFUS + CHOGSUS1 + CHOGSUS2 + CPOLTUS + CDAIRUS + COLVSUS

(52) COUXTUS == CIMPI + CIMPII + CIMPSU + CIMPIII + CIMPIV + CIMPROW - COUXTROW

(53) 0 == CLVSTKUS + CFOODUS + CSTKTUS + COUXTUS - CIMPUS - CPRDUS -CSTKTUS(-1)

The first (51) adds feed use of corn by livestock category including that fed to other types not explicitly considered elsewhere (COLVSUS). Total corn fed (CLVSTKUS) is equal to that fed to beef cattle (CBEEFUS), hogs in both semi-annual periods (CHOGSUS1 and CHOGSUS2), poultry (CPOLTUS), dairy cattle (CDAIRUS), and all other livestock (COLVSUS). This equation could be substituted into (53) but is kept separate to facilitate the retrieval of simulation results.

The purpose of identity (52) is to determine annual US corn exports and clear the world market to which the US is the residual supplier. The final equation in the model (53) ensures that the market clears in the aggregate and also thereby implicitly determines corn price through this equilibrating mechanism. Within the US, the sum of total corn fed to livestock (CLVSTKUS), used for food, seed, and industrial purposes (CFOODUS), held as ending stocks (CSTKTUS), and exported (COUXTUS) must equal the sum of corn imported (CIMPUS), produced (CPRDUS), and held as beginning stocks (CSTKTUS(-1)).

Model Validation

Having arrived at satisfactory estimates of the coefficients in the individual structural stochastic equations, the next step was to evaluate the model's performance as a whole. Its dynamic stability is considered first, then the use of simulation as a validation exercise is discussed.

Using the mathematics of difference equations, stability conditions for a linear, nonstochastic model can be described. In a stable system, all the variables eventually converge to equilibrium levels. Examination of the characteristic roots, calculated from the model's final form (and ultimately dependent on model parameters) will reveal the nature of the model's stability. It may or may not converge over time, and this path may be characterized by monotonic or oscillatory behavior or a combination of both. Model stability is important because it is the general perception that real world variables behave in a fundamentally stable fashion. Consequently, an acceptable empirical model will reflect this characteristic real world behavior.

If, however, the structural form of the model's equations are other than nonstochastic and linear, then no analytical solution to stability conditions can be found. The model at hand is nonstochastic and nonlinear. According to Labys, "There is little opportunity for directly determining the stability characteristics of such a model based on either simulation or analytical methods" (p. 173). Nevertheless, the validity of the model, meaning its ability to reproduce real world events, can be evaluated in another way via simulation, which is basically the numerical solution to the system of equations over time. Pindyck and Rubinfeld state, "By simulating the model during the period for which historical data for all variables are available, a comparison of the original data series with the simulated series for each endogenous variable can provide a useful test of the validity of the model" (p. 313). This procedure, which they call *ex post* or historical simulation, is used here.

> The simulation begins in year T_1 and runs forward (n years) until year T_2. Historical values in year T_1 are supplied as initial conditions for the endogenous variables and historical series beginning in T_1 and ending in T_2 are used for the exogenous variables. There is no 'reinitialization' of the endogenous variables; after year T_1 values for the endogenous variables are determined by the simulation solution.
>
> (p. 313)

The ex post and ex ante forecast (present to T_n) simulations of the model are discussed below. Historical simulation, which is often performed for the purpose of policy analysis, can be done using the reduced form if the model is linear. The nonlinearities (in the form of price ratios) in the present model prevent the use of the reduced form directly. Furthermore, the presence of lagged variables which are endogenous (although they appear in the reduced form) may also cause difficulties (Labys, p. 202). Consequently, the model must be simulated in its structural form, usually using an iterative solution procedure. The TROLL package used to estimate and simulate the model employs that of Newton, which allows a direct solution of a related set of equations after they have been ordered into a series of blocks (Massachusetts Institute of Technology, p. 8-8). If the model had contained nonlinearities more complex than products or quotients, an iterative algorithm, such as the Gauss-Seidel, would have had to have been used (Labys, p. 208).

The results of the historical simulation were compared to the original data series; using several criteria, the validity or performance of the model was judged to have been quite acceptable. These criteria are described, then the results are presented and evaluated qualitatively.

The annual difference between the historical and simulated values for any endogenous variable are evaluated using a measure of the mean square error, its decomposition, and Theil's U statistic. The root mean square (RMS) percent error is a measurement of the divergence of the simulated variable (S_t) from its actual value (A_t); its formula is

$$\text{RMS error} = \sqrt{\frac{1}{T}\sum_{t=1}^{T}\left[\frac{S_t - A_t}{A_{t-1}}\right]^2} \; .$$

The MSE (square of the expression above) can be decomposed into three constituent parts, which apportion the divergence between the two values among various sources. Let $s_t = (S_t - A_{t-1})/A_{t-1}$ and $a_t = (A_t - A_{t-1})/A_{t-1}$. The MSE expression can be written as $(\bar{s} - \bar{a})^2 + v^2_{s-a}$, where the second term is the variance of the simulation errors and the bar denotes the mean. The derivation of the three components given below from this expression is given by Maddala (p. 344-45). The correlation between s and a is denoted by r, and v_s and v_a are the standard deviations of the s_t and a_t, respectively.

$$U^M = \frac{(\bar{s} - \bar{a})^2}{MSE} = \text{bias proportion.}$$

$$U^R = \frac{(v_s - rv_a)^2}{MSE} = \text{regression proportion.}$$

$$U^D = \frac{(1 - r^2)\ v_a^2}{MSE} = \text{disturbance proportion.}$$

The sum of the three equals one.

A large value of the bias proportion, U^M, indicates that the average simulated change differs markedly from the average actual change, a situation which the modeler should be expected to be able to reduce. U^R is another measure of systematic error; both U^M AND U^R tend to zero for the optimal predictor. The disturbance proportion, U^D, is the variance of the residuals obtained by regressing the actual relative changes on the simulated changes (Maddala, p. 345). Since U^M and U^R tend to zero for the optimal predictor, the larger U^D the better the simulation performance. A high U^D value indicates that the simulation reproduced deterministic movement in the actual variables and the low remaining discrepancy is due to stochastic influences, which the original regression could not capture anyway.

Another criterion used in the evaluation of the historical simulation was Theil's U1 statistic, defined as (Maddala, p. 346)

$$U1 = \sqrt{\frac{MSE}{(\Sigma A_t^2)/N}} \quad .$$

Here, the A's are the actual historical values and MSE is as given above. Its value tends to zero for perfect forecasts and is equal to one when the simulation coincides with that of a naive no-change extrapolation. Theil explains,

> ...by using the inequality coefficient one measures the seriousness of a prediction error by the quadratic loss criterion... in such a way that the zero corresponds with perfection and the unit with the loss associated with no-change extrapolation... the inequality coefficient has no finite upper bound, which is tantamount to saying that it is possible to do considerably worse than by extrapolating on a no-change basis.
>
> (p. 28)

The values for these statistics for each endogenous variable are presented in Table 6. Examining the results for some of the more important variables, such as prices, the average root MSE is 18 percent, compared to an average of 12 percent for all endogenous variables. The relatively poor simulation of prices is not surprising since they adjust to quantity changes and tend to move more erratically than the quantity variables. Arzac and Wilkinson's dynamic simulation shows prices to have performed most poorly also (p. 303). In particular, corn price (COPFUSDT) has a rather large root MSE of 23 percent, although U^D shows that half this deviation is attributable to random movement not captured by the deterministic simulation. Other prices which have fluctuated quite markedly are feeder cattle price (FCPKCUS) and hog prices (BGPFUS1 and BGPFUS2); the model had relatively more difficulty tracking these variables, although, again, U^D shows the importance of the stochastic element in explaining these discrepancies.

The historical fluctuation in these prices is attributable at least partially to movements in factors which are exogenous to this model. Here, the prices represent the results of adjustment in supply and demand, and, for corn, stocks. In practice, annual equilibrium may not be so neatly achieved; the speculative influence in the futures market, for example, may affect market events. Furthermore, corn and livestock vary regionally and in response to developments in the macroeconomy; the equilibrium price as determined by the model does not reflect this.

SIMULATION ANALYSIS

The post-estimation and post-validation analysis of the corn/livestock model has two purposes, both of which can be accomplished through the application of Monte Carlo techniques in stochastic simulation. These are

(1) to predict the paths of key variables in the corn market given stability over the next decade; and

(2) to evaluate the possible effects of volatile Soviet imports upon the market in the future.

The information obtained from this part of the analysis will provide a picture of the likely events in the corn market with no change in US export or agricultural policy. As Thompson states, "...it is essential to keep in mind the objective of making long term projections, namely identifying what will happen if present trends continue. The reason for doing this is to identify potential problems such that policy changes can be implemented in time to avoid undesirable consequences" (p. 49).

Projecting the paths of key variables in the market assuming stability provides a base case against which to consider the changes which occur when the influence of stochastic events, here Soviet imports, is introduced. The prices of corn and livestock are singled out for examination in this context. Thus, the projection reflects only systematic movement in the market. In the

Table 6 Validation results a/

VARIABLE	ROOT MSE	MSE DECOMPOSITION UM	UR	UD	THEIL'S U1
	--------percent----------				
Production and stocks					
COPFUSDT	23	0	48	50	1.20
CSTKTUS	27	3	30	67	0.67
COAPLUS	5	1	33	66	0.74
COAHGUS	5	1	30	69	0.73
CYLDGUS	4	0	4	96	0.40
CPRDUS	6	0	2	98	0.40
Domestic US disappearance					
CBEEFUS	34	6	75	17	1.90
CHOGSUS1	8	1	40	58	0.97
CHOGSUS2	10	7	18	75	0.75
CPOLTUS	8	0	30	70	1.02
CDAIRUS	7	0	19	81	0.78
CFOODUS	4	5	58	36	0.88
World corn imports					
CIMPI	18	2	48	50	0.97
CIMPII	45	4	53	42	0.99
CIMPIII	7	10	6	84	0.58
CIMPIV	22	0	8	91	0.75
COUXTUS	14	0	32	68	0.53
Poultry					
BRPRDUS	6	0	50	40	0.92
BRCONPC	6	0	51	49	1.03
Beef					
BFCOWINV	2	42	5	51	0.84
CLFCROP	2	65	3	32	0.76
HFADD	7	37	0	63	0.73
NETCROP	7	30	25	45	0.69
COWSLUS	14	12	7	81	0.71
FCAVLWT	3	1	49	50	0.30
FBSLUS	12	0	70	30	1.60
NFBSLUS	35	0	37	63	1.20
FBAVLWT	3	1	48	51	1.34
FBPRDUS	15	0	70	30	1.60
NFBPRDUS	18	3	9	88	0.73
FBCONPC	14	0	70	30	1.67
NFBCONPC	18	3	9	88	0.73

Table 6 Validation results (continued)

VARIABLE	ROOT MSE	MSE DECOMPOSITION UM	UR	UD	THEIL'S U1
	--------percent-----------				
Hogs					
HGBINV2	8	0	44	56	0.92
SOWFAR1	8	0	54	46	0.88
SOWFAR2	7	1	25	74	0.75
PCROP1	9	0	53	46	0.94
PCROP2	7	0	28	72	0.78
BGSLUS1	8	2	28	70	0.77
BGSLUS2	11	6	35	57	0.98
SOWSLUS1	18	0	54	46	1.16
SOWSLUS2	14	0	18	82	0.75
GADD1	12	0	5	95	0.53
GADD2	13	1	11	88	0.63
PKCONPC	8	15	40	55	0.97
PKCONPC1	8	1	36	63	0.89
PKCONPC2	10	7	28	65	0.87
Prices					
POPFMUS	10	1	1	98	0.67
FCPKCUS	20	2	36	62	1.08
FBCPUS	12	4	46	50	0.97
NFBPUS	12	18	14	68	0.65
BGPFUS1	19	3	29	67	0.86
BGPFUS2	31	3	47	49	1.02

a/ Refer to text for definitions of validation statistics.

real world, random as well as systematic movement in any or all of the variables is possible; these deviations from the projected deterministic paths would necessarily have an impact on the levels of the key variables. Still the analysis will provide a useful benchmark for comparison with future analysis and real world events.

The possible effect of volatile Soviet imports are examined by assuming that the only source of random fluctuation in the market over the decade is USSR import behavior. This approach will understate the potential instability in the market, which could plausibly arise from variance in US production or other countries' imports or any number of sources, both endogenous and exogenous to the current model. However, by limiting destabilizing behavior to that of the USSR, the empirical analysis can focus on the specific impact of future variable Soviet demand on the market. This potential impact can be isolated by comparing these projections to that obtained under the assumption of complete market stability.

Stochastic simulation, which employs Monte Carlo methods to draw random values, is an appropriate means of achieving the two aims of this analysis since the events of the next decade cannot be predicted with certainty. The deterministic paths of the model's exogenous variables are projected over the period 1980/81 to 1989/90. While any combination or all of these variables could be subjected to Monte Carlo generation, in the present analysis only Soviet imports follow a stochastic path. For each randomly determined value of Soviet imports, there are a unique set of values for the endogenous variables which solve the model. By repeatedly drawing values for Soviet imports, a distribution of values for each endogenous variable is obtained. Mean levels and estimates of likely fluctuation of the variables can be obtained from these distributions, both over the entire forecast period and for each year within the forecast.

The mean levels of the variables derived from the Monte Carlo analysis represent their projected paths under conditions of stability. In particular, Soviet imports follow a deterministic path represented in the mean level of the results from all the stochastic simulations. Consequently, the paths of the corn and livestock prices will reflect only projected systematic movement in the market in the 1980s.

To look specifically at the potential impact of Soviet-sourced instability, one of the stochastic simulation trials is examined in detail. The chosen run represents an extreme case of Soviet import behavior, selected from among the others because of the magnitude and sequence of fluctuations in Soviet imports. In particular, large imports occur at the next peak of the cattle cycle. In the analysis of this experiment, the behavior of the other market variables, in addition to prices, is discussed.

An explanation of the assumptions and methodology used to predict the future path of Soviet imports of corn is given in the next section. The extrapolated paths of the model's other exogenous variables are presented following that. Then, the paths of the seven key price variables, as found from repeated simulation of the model, are analyzed. Next, the paths of all the model's endogenous variables are examined in detail, using the results of one of the stochastic trials to focus on the effects of Soviet-originated instability. Finally, some comments on the accuracy of the projections and suggestions for further experimentation are offered.

Soviet Corn Import Projection

In order to project the effects on the world corn market of future Soviet grain imports, Monte Carlo techniques are applied to the econometric model. In this exercise, "artificial experience or data are generated by the use of some random number generator and the cumulative probability distribution of interest...the random numbers are used to produce a randomized stream of variates that will duplicate the expected experience, which would be produced by the probability distribution being sampled" (Shannon, p. 65).

In the experiment at hand, the probability distribution of interest is that of deviations from trend of Soviet grain production. Historical trend is estimated by OLS regression; the error term is presumed to be normally distributed with mean zero. It is from the parameters of this distribution, using random normal numbers generated by TROLL, that yearly values for deviations from Soviet production trend over the next ten years are generated. Using these production figures and estimates of annual grain use, projected corn imports are calculated and entered as exogenous data in simulation. The forecast period covers 1980/81 to 1989/90. Values of the exogenous variables are extrapolated over these ten years, their projections based on assumptions presented below. Although crop year data for 1980/81 (as well as preliminary 1981/82) were available, that for calendar year 1981 was not, so this year is projected and simulated as a test of the model's predictive accuracy.

In order to project the possible future path of Soviet corn imports, it is necessary to make some assumptions about future grain use and production. Corn imports are not predicted from an import demand equation, but from a function of the difference between projected use and projected production.

Grain use in the Soviet Union is a function of livestock production and other needs (food, seed, and industrial). Livestock production, in turn, is determined by policy decisions, as embodied in Five Year Plans. Often these announced goals are not realistic projections of economic capabilities, as has certainly been the case with Soviet meat forecasts. For 1980-1985, the announced intention is to increase the supply of livestock products by 1.5 percent per capita annually (CIA, p. 2). However, the growth rate in the 1970s, when a firm commitment to a more consumer-oriented agricultural policy was made, averaged only about one percent. Even so, the announced output goals are low considering the strength of consumer demand for meat products. Here, the assumption is made that no matter what the promulgated goal, growth in livestock production is maintained only at the 1970s growth rate of one percent annually. (In contrast, the rate of the 1960s was almost five percent, but starting, of course, from a much lower base.)

Feed use of grain can be expected to grow in both absolute and relative importance over the next decade. Currently, about 9 MMT of grain are required to produce 1 MMT of meat production (beef, veal, and pork) in the Soviet Union (CIA, Appendix B). Using this concentrate conversion factor and allowing for grain use by horses (still in significant draft use) and other livestock (poultry, goats, sheep), the required levels of grain supply have been derived. The calculations show that the total grain supply must grow at about one percent per year to sustain one percent annual increase in livestock production. The validity of this derivation rests upon the accuracy and constancy of the estimate of the feed conversion rate. Considering the diversity in feeding practices within and among livestock sectors, the 9 MMT figure can only be an average, although it has remained fairly constant over the past decade.

Estimation of trend growth in Soviet grain production is done using OLS regression over the period 1960-1979.

$$\text{TOTAL GRAIN PRODUCTION} = \underset{(10.42)}{111.16} + \underset{(0.87)}{4.50} * \text{TIME}$$

$$\bar{R}^2 = 0.57$$

The extremely variable nature of Soviet grain production accounts for the rather low coefficient of determination, which reflects the influence of the several large outliers. The coefficient of linear trend implies an average annual rate of trend growth of about 2.8 percent, relative to the mean, 158.43 MMT, with a standard deviation of 15 percent. Assuming the error term to be normally distributed, with mean zero and standard deviation of 22.45 MMT, random normal numbers are used to predict stochastic deviations from trend production each year. These values are then added to or subtracted from the projected trend production.

Trend production values are calculated using the equation above until 1985/86, when the mean level of production is presumed to level off. In its appraisal of Soviet agricultural prospects, the CIA advances reasons for expecting this plateau to be reached. First, the Agency notes, "(A)rea sown to all crops in 1985 is planned to be only fractionally higher than it was in 1975. Fallow land has already been reduced to a minimum, and there is, in fact, little potential for bringing new land into production" (p. 3). Consequently, increases in production will be achieved through increased application of fertilizer and through other "technological advances such as improved mechanization, expansion of irrigated areas sown to grain and the development of better varieties, which would increase yield and reduce variation resulting from fluctuating weather conditions" (CIA, p. 3). The land constraint and limits on successful technologically-based improvements mean further increases in trend yield beyond the 1985/86 level will be difficult to achieve.

The attainment of even trend production levels depends on the weather, the greatest source of variability in Soviet agriculture. As noted earlier, the standard deviation around trend was 22 MMT over the past twenty years, but it was even higher, about 28 MMT, over the past ten. It may be that the past two decades were a stretch of abnormally good weather, and a return to a more nearly normal pattern interspersed with good and bad years may be in store for the 1980s (CIA, p. 3). In that case, the trend estimates would be somewhat optimistic and the expected variance perhaps understated. The estimates of trend production and variability used here correspond closely to the CIA's assessment in the report cited.

A factor which accounts for the proportion of grain shortfall which is met by imports is included in the forecasts to damp the effects on the grain markets of extremely poor harvests. Then, some adjustments in the livestock sector would probably be made in lieu of massive imports. A case in point is 1975/76 when grain production was 132 MMT, 50 MMT less than the previous year. To cover this deficit, some 25 MMT of grain were imported, and grain use was decreased about 20 MMT from the previous year. As an arbitrary figure, but one with some basis as an historical average, 75 percent is chosen as the proportion of shortfall that would be met by imports. This formulation does not directly allow for the simultaneity that exists between grain use and availability, a relationship which implies adjustment in the livestock sector, as through distress slaughtering in 1975/76.

Grain imports of the Soviet Union consist mainly of wheat and corn. Historically, corn was about eight percent of total grain imports in the 1960s, 40 percent in the 1970s, and about 50 percent over theperiod 1975/76 to 1979/80. Corn and wheat have essentially the same nutritional feeding qualities, and thus, as substitutes, their import shares might be expected to be determined by relative prices. To a certain extent this appears to have been the case. However, the mix is also influenced by feeding practices in the USSR, which utilize primarily wheat. In the projections for the 1980s, then, it is assumed that half of all grain imports will be corn and the other half wheat.

The level of Soviet imports of corn in any period (CIMPSU) is calculated using the equation below.

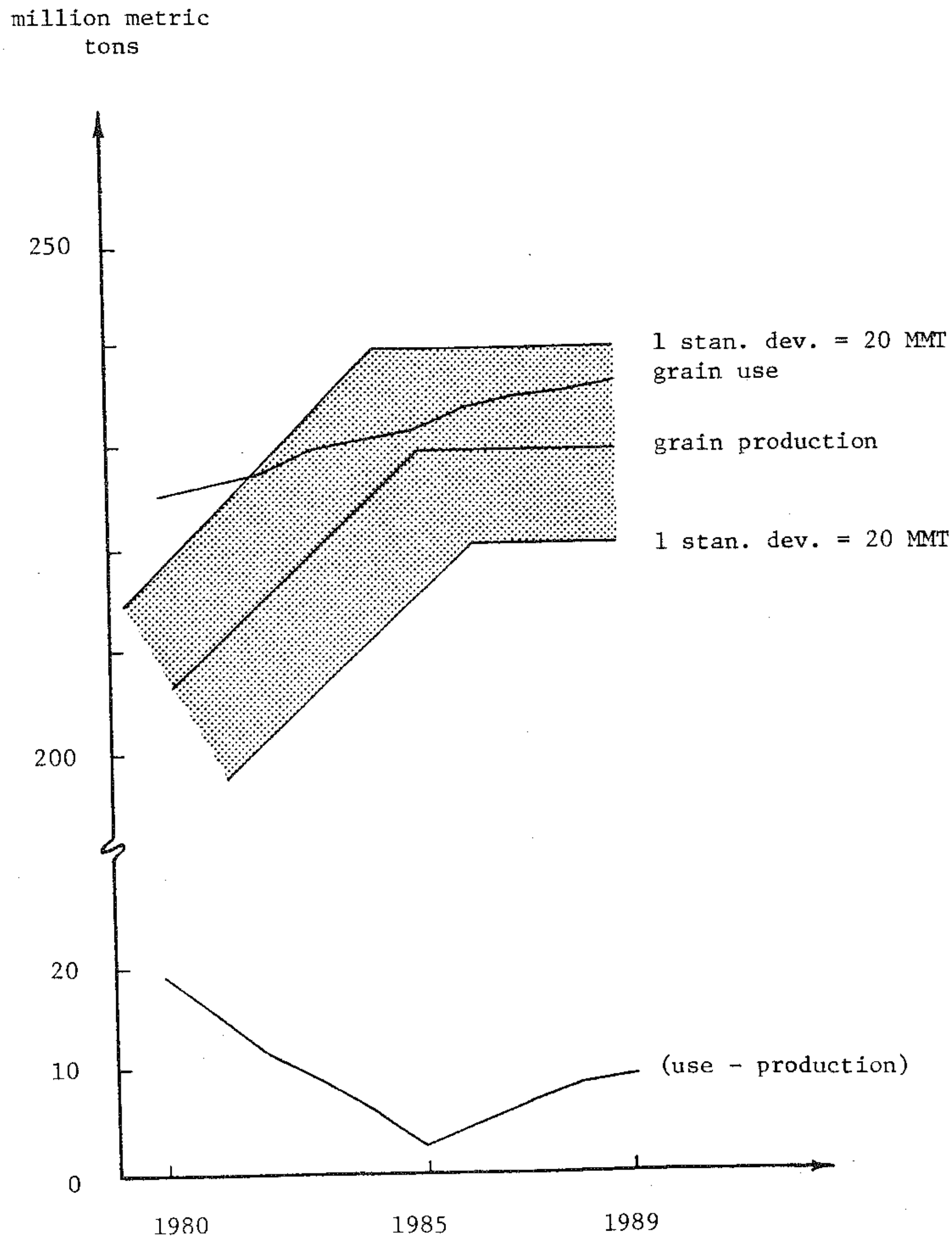
$$\text{CIMPSU} = (\text{GRAIN USE} - (\text{TREND PRODUCTION} + e))\ (0.75)\ (0.50)$$

where

e = randomly drawn value from the probability distribution of historical deviations from trend grain production.

Figure 7 depicts the situation in the 1980s implied by these assumptions. By 1989/90, livestock production has expanded to a level about ten percent over that at the start of the decade, while production trend increases until the middle of the decade when it levels off. The shaded area represents one standard deviation (22.4 MMT) either side of trend production. At the bottom of the graph, the difference between projected use and trend production indicates that the shortfall will decrease until 1985/86 and then begin to climb again. Because of the large possible deviations around trend, the shortfall could very likely be must larger than that indicated in the figure.

Figure 7 USSR projected grain shortfall



Exogenous Variable Projection

The paths of the remaining 24 exogenous variables in the model must be extrapolated over the forecast period. These variables deal with forces in the export sector, technical aspects of livestock production, the corn production and policy sector, and macroeconomic influences. These groups are discussed in turn to provide an explanation for the projected behavior of each of the variables over the period 1980/81 to 1989/90.

The foreign demand for corn is determined largely by influences exogenous to the corn market itself. In particular, corn price plays a rather insignificant role, and import demand for corn depends most strongly on the difference between domestic demand and supply. In the European Community, coarse grain production (CGPRDIII) is assumed to grow at the rate of the 1970s, about 2.2 percent annually. This is perhaps an optimistic estimate, but one which assumes that the EC can take advantage of any future technological advancements in the production of grain. EC livestock production (LVSTKIII) grew 2.3 percent each year over the past decade. Since the demand for meat tends to be income elastic, its projection depends on the future course of income and also on the constancy of income elasticity. Consequently, projecting LVSTKIII to grow during the 1980s at the rate of the 1970s implies incomes continue to grow at the same pace (a dubious proposition) and that the income elasticity (estimated to be 0.6 for beef and 0.5 for pork (Rojko, et al., p. 88) is constant. However, EC per capita consumption levels are currently 10 to 20 percent below those of the United States. The US income elasticity is somewhat lower than that of the EC (0.4 for beef, 0.3 for pork (Rojko, et al., p. 88). It is assumed income elasticity will not fall until the EC reaches US consumption levels. No matter what, population increase will continue to buoy aggregate demand for meat and livestock products.

The countries of Group I (Mexico, Malaysia, Japan, South Korea, Taiwan, Israel, and Egypt) are expected to continue to be the most dynamic sector of the international corn market. Their demand is projected to grow with increases in their livestock production at an annual pace of six percent through the 1980s. The 1970s growth rate was seven percent, but it is presumed that Japanese consumption, already substantially above the levels of the other countries, begins to level off and that neither Israel nor Egypt exhibit strong expansion in utilization.

The overall picture in the 1980s for the Eastern European bloc countries assumes that they will not quite manage to hold the growth rates of the previous decade. While coarse grain production (CGPRDII) averaged an annual increase of two percent during that time, most of the gains were made in the early part of the decade; the 1973/74 to 1979/80 rate was only 1.6 percent. Here, it is assumed that CGPRDII grows at 1.5 percent per year. Similarly, livestock production grows at only one percent per year. Over the 1970s, there was an average annual increase of almost five percent, but, as with coarse grain production, most of the gains were made in the early years, as the 1973/74 to 1979/80 growth rate was only 1.5 percent. This latter figure is adjusted downward even further for extrapolation because of expected continued difficulties in Poland. Poland is a major livestock producer and also, of all the Eastern European countries, imports the most corn from the West.

Corn exports by the rest of the world (COUXTROW) come primarily from Argentina, South Africa, and Thailand. In general, there is presumed to be little possibility of significant expansion in the aggregate, and this implies that growth of exports from the three continues at its 1970s level of one percent per year, versus a three percent rate over the period 1960 to 1979. This overall growth rate implies that Argentina just keeps pace with its 1970s rate, South Africa falls from its almost nine percent rate, and Thailand falls from its four percent rate. The lower rate also implicitly incorporates a discount for the variability in supply by the other exporters, principally due to instability in Argentine production. Corn imports by the United States (CIMPUS) are held constant at their average historical levels of 0.025 MMT.

Various technical factors and relationships in the livestock production sectors have been designated constants or as exogenous vectors in the estimation of the model. The cattle sector contains a number of these exogenous influences which must be extrapolated through the 1980s. Calf death loss (CLFDLOSS) has averaged about ten percent of the calf crop (CLFCROP) since 1960 and is projected to continue at that rate. Calf slaughter (CLFSLUS) fell about six percent annually in the 1960s and by four percent in the 1970s. While calf slaughter depends on the price of veal and consumer preferences as well as production alternatives, CLFSLUS is simply extrapolated to continue at its 1979/80 level of about 2 million head, a figure close to its 1970s average.

One of the most important exogenous characteristics of the model's cattle sector is the cycle imposed through the use of the DLIQ variable, which has values equal to one in the liquidation phase. Peaks in cattle numbers have occurred at ten year intervals, and this sequence is projected to recur in the next decade. The dummies occur in the years 1984/85 through 1987/88, including the projected peak year and a year shorter decline than in the 1970s (an especially severe liquidation historically).

Nonfed beef average dressed weight (NFBAVDWT) was calculated by dividing nonfed beef production by the number of head of nonfed beef slaughtered. While this weight is not constant over the historical period, it does remain in a reasonable range, somewhat below the weight of fed beef, as would be expected. The fluctuation within the range appears to follow the pattern of the cattle cycle, weights increasing with buildup, reaching their highest point at the peak of the cycle, and declining during the liquidation phase. Given that NFBAVDWT is a constructed variable to begin with, it is risky to attach any structural explanation to its course, although there is a plausible explanation. Nonfed beef slaughter declines in the buildup phase of the cycle and then increases at the peak and in liquidation, when breeding inventory is drawn down. Weights are inversely related to slaughter numbers, then, indicating that perhaps with the lower cattle prices implied by increased supplies, nonfed cattle are not held on forage as long and so are not as heavy as they might be if prices were higher. For the 1980s extrapolation, then, NFBAVDWT varies with the projected cattle cycle as imposed through the use of DLIQ.

Neither the average amount of corn fed per head of hogs (CHOGAV) nor the average dressed weight of hogs (HGAVDWT) varied significantly in the 1970s.

Thus, they are projected to remain at their 1979/80 levels, assuming the absence of any dramatic changes in feeding efficiency. CHOGAV is constant at 0.43 MT of corn fed per hog and HGAVDWT stays at 171 pounds. Corn fed to horses, sheep, goats, and other livestock (COLVSUS) has averaged about 2 MMT per year since 1970 and is projected to remain at this level through the 1980s.

There are three exogenous variables in the corn production and policy sector: corn area set aside (COASAUST); corn loan rate (COPLDT); and soybean price (SOYPUSDT). The set aside and the loan rate are policy variables which are, to some extent, influenced by past and present market conditions. Since, however, in this model they are not explained endogenously, some simple projections are made. With continued high demand for corn, it is presumed that set aside will not reach the levels of the 1960s, but will probably not be zero (given the interest in federal budget restraint). So, its value is arbitrarily set to remain at a constant 2 million hectares each year, a figure which is about the average after normal and below normal crop years in the 1970s. The nominal loan rate increases at six percent per year. This projection is used on target prices expected to be incorporated in the 1981 farm bill, still in committee at the time of the simulation. Soybean price is fixed at its 1979/80 nominal level of $227.44 per MT.

The exogenous variables which reflect the interface between the agricultural sector and the macroeconomy are among the most important and most difficult quantities to predict. In general, conservative assumptions are made. Disposable income is projected to grow at one percent per year. The two price indices (PPIUS for producers' costs and PP7PZ for fertilizer) are fixed at their 1979/80 levels; thus the output of the forecast simulation will be in constant 1980 dollars. While it can be argued that 1980 was an anomalous year, even by the standards of the 1970s, it is chosen to provide a basis for comparison. Relative variability, not absolute levels, of price is of most interest in the current experiment. Population is projected to continue to grow at the annual 0.8 percent rate of the 1970s.

Results

In the Monte Carlo experiment, 100 simulations of the model were performed for the period 1980/81 to 1989/90. The values of the exogenous variables used were as described in the previous section. One hundred ten-year long vectors of values for Soviet corn imports were generated by the process outlined earlier. Each of these import vectors were then entered one at a time as exogenous data (CIMPSU) in simulation, and the model solved. Summary statistics for seven important price variables were calculted from the results of the 100 trials. Then, for one of the 100 simulations, the values of all the projected endogenous variables were retrieved as a means of examining the projected behavior of the physical quantity variables when Soviet imports are particularly volatile.

Summary results for price variables and Soviet imports

The seven price variables which were collected from each of the 100 simulations, are the prices of corn (COPFUSDT), fed beef cattle (FBCPUS), nonfed beef cattle (NFBPUS), feeder cattle (FCPKCUS), barrows and gilts in the first and second halves of the year (BGPFUS1 and BGPFUS2), and broilers (POPFMUS). For each price series, the estimated mean and standard deviation over the ten year period were calculated. In addition, for each year, the estimated mean, standard deviation, and maximum and minimum values over the 100 trials were found. All prices are in 1980 dollars.

First, the generated values of Soviet corn imports are summarized in Table 7. The 1980-1989 mean was 5.35 MMT annually. The annual means decrease until the mid-eighties and then turn up again. Note that, by construction, the minimum value of the imports is in all years zero. This can be explained with reference to the procedure used to generate these values. When the random trend deviations for a ten year period are drawn, it is possible that Soviet grain production could exceed use. However, it seems implausible that the Soviets are likely to become net exporters of corn, unless they be to the other bloc countries. The size of the production overage, in any case, would not be expected to be much more than 8 MMT and probably much less. Consequently, an excess of this amount might be used to replenish working stocks, but would not be expected to encourage significant expansion of the livestock sector or of security stocks. Therefore, there would be no appreciable effect on the carry-in and availability of corn for the next year. These assumptions allow yearly imports to be considered as independent from each other and dependent only on that one year's projected use and production. The effect of the truncation on the data used in each of the simulations is to raise the mean and lower the standard deviation from their expected values in the presence of negative values for imports.

Given the rather modest demands on the world market implied by these mean Soviet import levels, it is not surprising that the behavior of the seven price variables is not very erratic. Figure 8 displays corn price in 1980 dollars and Soviet imports, the shaded areas around the trend lines representing one standard deviation on either side. The mean level of corn price increases by about 12 percent over that of 1979/80, peaking in mid-decade primarily because of demand pressure at the height of the cattle cycle. It is a fortuitous coincidence that, just when US needs are largest, Soviet demand is at or around its mimimum level over the period. The minimum point at 1985/86 does seem to ease markedly the upward pressure on corn price. However, the standard deviations and the band around the projected means allow for wide variation in both corn price and Soviet imports; the effects of extreme values are examined in detail in the discussion of the one fully reported simulation.

The results for the beef sector prices are displayed, along with corn price, in Figure 9. Fed and nonfed beef price (FBCPUS and NFBPUS, respectively) do not change markedly from their 1979/80 levels, save for decreases with the peak and liquidation phase of the cattle cycle; their standard deviations are also rather small. In contrast, feeder cattle price (FCPKCUS) appears much more volatile, displaying more erratic behavior in mean and a much larger standard deviation each year than either FBCPUS or NFBPUS. For the most part, feeder cattle price displays a negative relationship with corn price. The burden of adjustment to instability in corn and livestock markets appears to occur at the level of cow-calf production. The fed and nonfed beef prices are

Table 7 Summary statistics for Soviet corn imports (MMT)

	Mean	Max	Min	Standard Deviation
1980/81	8.32	27.04	0	7.56
1981/82	7.20	22.80	0	6.33
1982/83	5.70	24.65	0	5.54
1983/84	4.49	19.68	0	5.28
1984/85	4.59	22.22	0	5.27
1985/86	3.56	19.96	0	4.81
1986/87	4.49	23.01	0	5.42
1987/88	4.73	23.00	0	5.53
1988/89	5.19	35.05	0	6.83

Figure 8 Mean projected corn price and Soviet corn imports

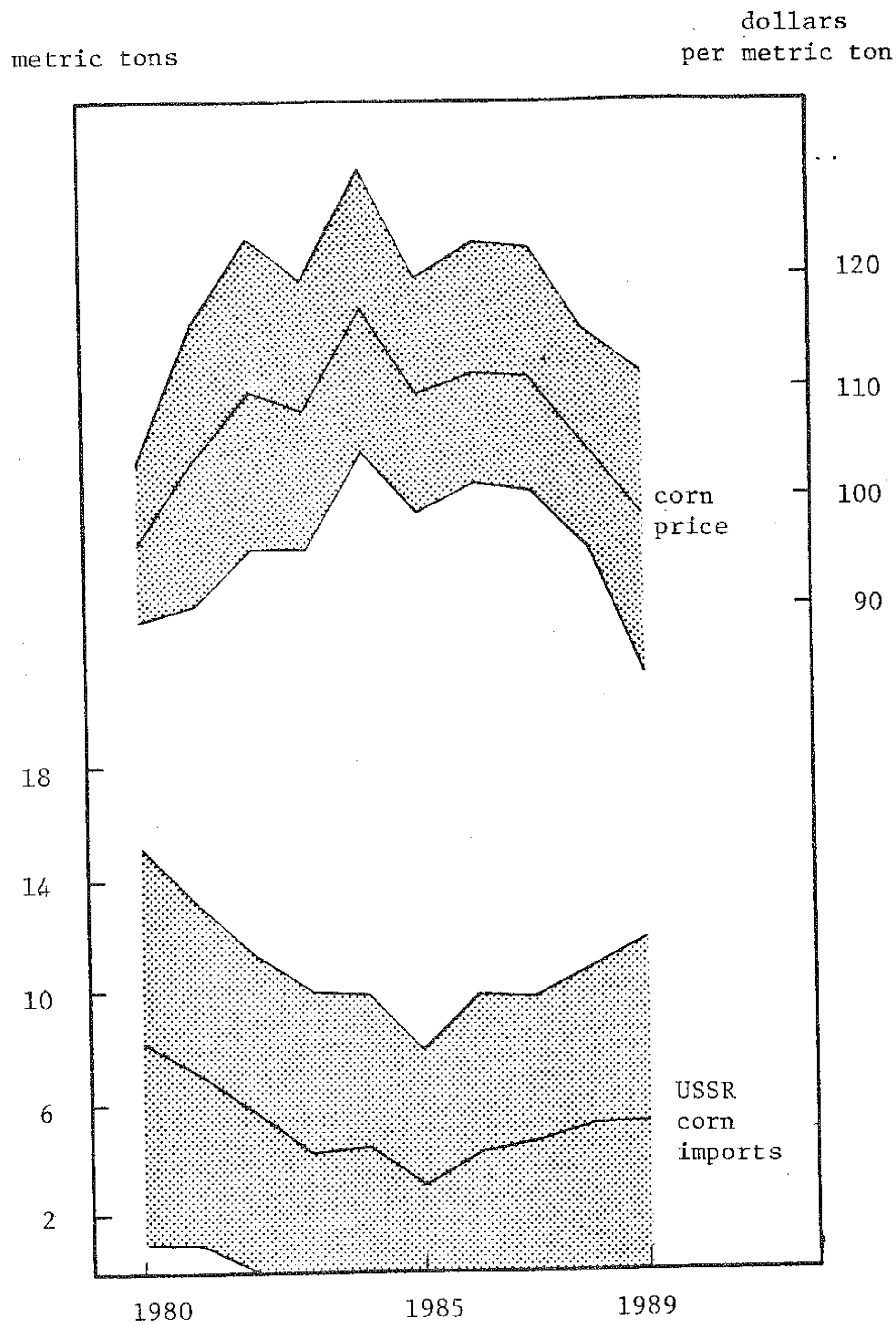
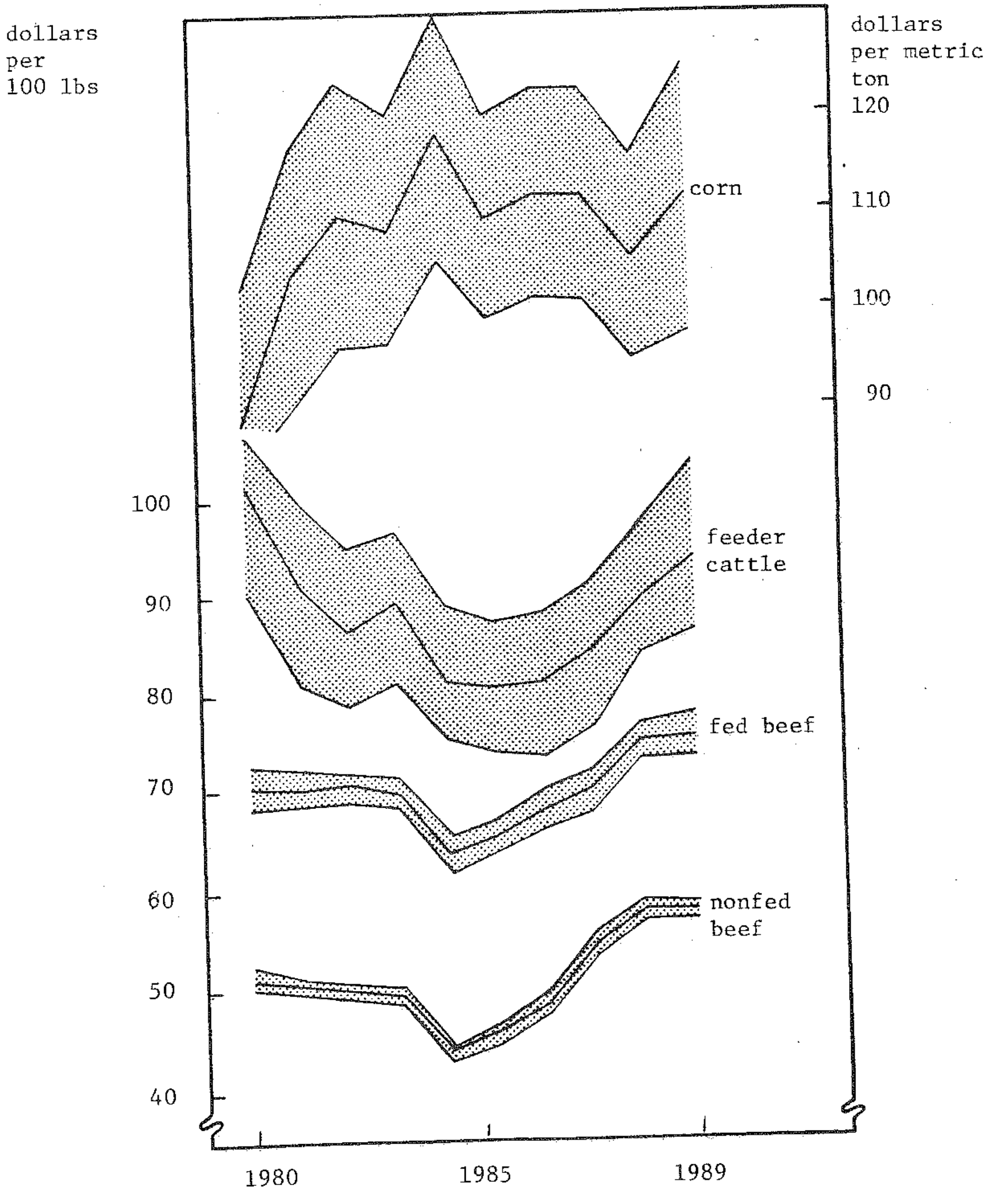


Figure 9   Mean projected corn and cattle prices



determined in the wholesale market, where the presence of other meat substitutes tends to moderate price fluctuation. The cow-calf producer, however, is essentially a price-taker in the feeder cattle market, where price is determined in feedlot operators' bidding by the relationship between fed beef and corn prices. Therefore, with relatively stable fed beef prices, the instability in corn price is transmitted to the feeder cattle price, so that cow-calf producers face a highly volatile output price. This volatility is particularly a problem because cow-calf producers must make forecasts about the price they expect to receive two or three years later for the offspring of a cow bred today. Consequently, the effects of risk-aversion on producers' decisions could likely result in a less than optimal supply of cattle.

Average broiler price over the 10 year period is five dollars above its 1979/80 value of \$27.80/100 lbs., and prices for first and second half barrows and gilts run ten to twenty dollars above their 1979/80 values of \$56.77 and \$57.73/100 lbs., respectively. The difference between the two hog price levels is attributable to inventory adjustment which occurs in mid-year based on certain knowledge of season corn price. The real price of broilers declines slightly over the period, due to increased supply. Production levels in the other meat sectors, by contrast, do not rise much over their 1970s levels so their prices are rather more buoyant (see discussion of full simulation below).

The projected paths of mean broiler and hog prices are smooth, smoother than those of the beef cattle prices, due to shorter production cycles. Adjustment to increases in corn and other input prices can generally occur within the year in the broiler industry, and somewhat less rapidly in the hog sector, in which there are only two pig crops per year. This is in contrast to the beef cattle sector in which, because of the length of the gestation period, there can be only one calf crop annually. Furthermore, the new-born calf is not ready to be moved to the feedlots for at least another year. As noted earlier, this biologically-based rigidity in cattle production contributes greatly to instability in feeder cattle prices.

Full simulation results

Greater insight into the forces determining the prices' behavior can be obtained by examining the projected paths of all the endogenous and definition variables, the physical quantity as well as value variables. Because the costs of retrieving and summarizing results for all variables over all 100 simulations are prohibitive, only the full results of one simulation are examined. After the 100 simulations, the trial which produced the greatest extremes in Soviet production and imports, and thus corn price, was selected for detailed inspection. The values for Soviet grain production and corn imports for each year in this case are given in Table 8.

In three of the ten years (1981/82, 1983/84, 1987/88), import levels of corn would be below those stipulated as minimum if there were to be an extension of the current bilateral agreement, which implies a minimum USSR import level of 3 to 4 MMT of US corn. Imposing that rather small minimum on the import

Table 8 Extreme case Soviet grain production and corn imports (MMT)

	Grain Production	Corn Imports
1980/81	181	17.0
1981/82	226	0.3
1982/83	192	14.0
1983/84	221	3.0
1984/85	199	12.0
1985/86	179	20.0
1986/87	219	5.0
1987/88	235	0.0
1988/89	221	5.0
1989/90	144	35.0

vector would not have an appreciable impact on the results and would have complicated the simulation process. In any event, this approach allows an examination of possible Soviet import behavior in the absence of restraints.

The projected behavior of corn and beef prices is graphed in Figure 10. As in the mean projected levels, fed and nonfed beef prices are relatively stable, while corn and feeder cattle prices fluctuate strongly and in opposite directions. The disasterously low Soviet harvest of 144 MMT in 1989/90 causes the large increase in corn price (and corresponding decrease in feeder cattle price), when Soviet corn imports are 35 MMT, representing 30 percent of world corn imports that year (out of 120 MMT total, 100 of which come from the United States).

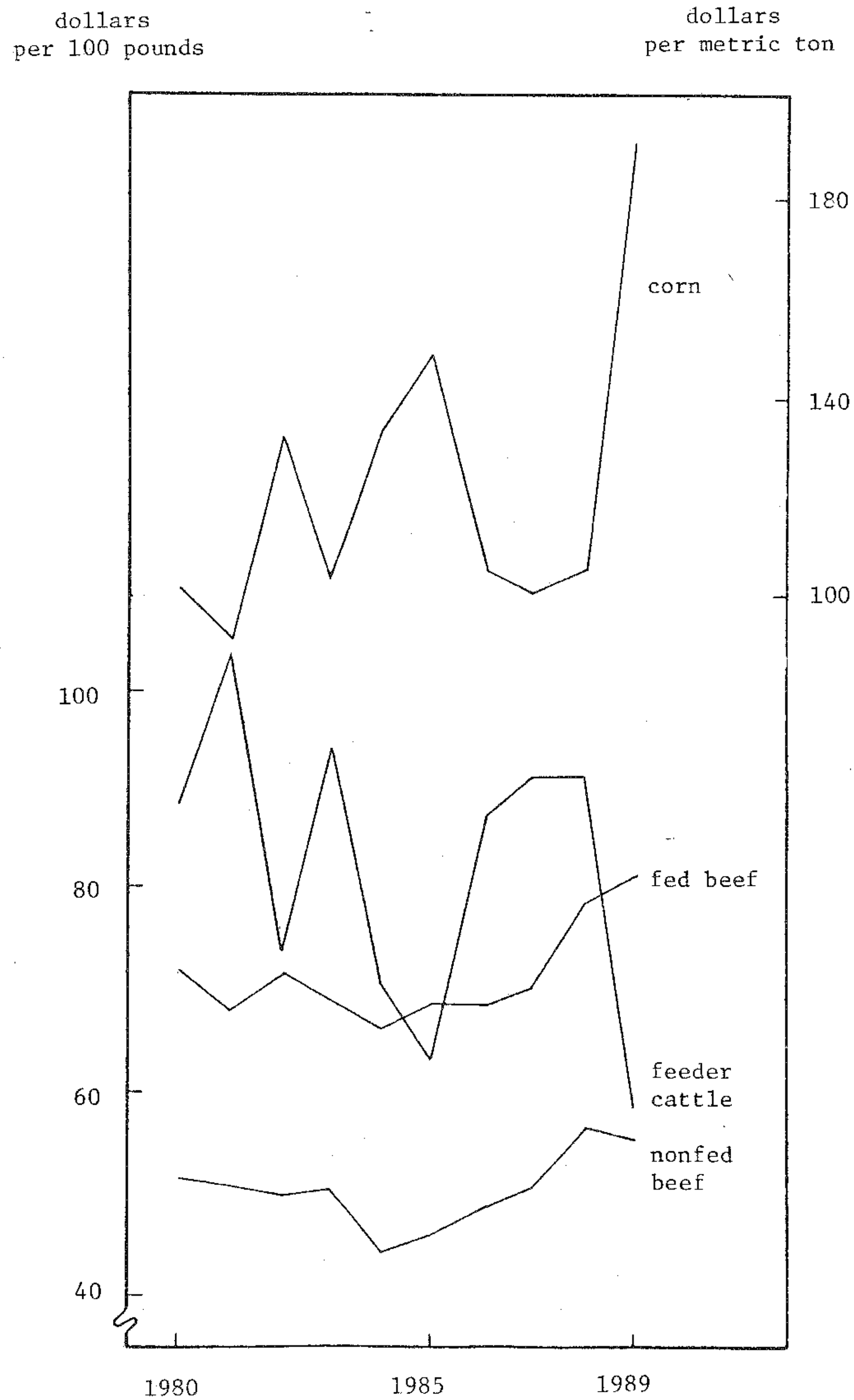
In this simulation, there are plausibly large Soviet imports of 20 MMT in 1985/86, at the top of the US cattle cycle, and consequently a strong increase in corn price as domestic livestock demand competes for the available corn supply. There is a sharp drop in fed beef production and an increase in nonfed beef production, as steers and heifers bypass the feedlots due to low feeder cattle prices. As a result, per capita fed and nonfed beef consumption is reduced to 111 pounds in 1985/86, in contrast to levels of 120 pounds the immediately preceding and following years. Neither pork nor broiler consumption expand to fill the deficit.

Feeder cattle price falls below fed beef price in 1985/86, relative price behavior which is typical around the peak of the cattle cycle, when there is a large supply of steers and heifers. This phenomenon occurs during the sixties' cycle peak (1963-1965) and the seventies' (1973-1975). While normally this relationship could be expected to make feeding beef an attractive proposition, sharp increases in corn price wipe out the potential for making money on the feeding margin. Around the peak of the last cattle cycle, this favorable cattle price relationship prevailed, but, as in this simulation, corn price increases sharply.

In contrast, average broiler consumption in the 1980s rises and is projected at 52 pounds per capita, a nine pound increase over the 1970s level of 43, and almost 20 over the 1960s level of 33 pounds. The production increase occurs smoothly over the ten year period from 15 billion pounds in 1980/81 to 18.5 billion pounds in 1979/80. This increase results in the decline of the real price of broilers from $32.80 at the start to $31.63 per hundred pounds at the end of the period.

These supply patterns of livestock products are reflected in the distribution of corn use by livestock category. On the average, about 104 MMT are fed to livestock each year. Dairying consistently accounts for about 18 percent of the total, other livestock for 2 percent, and poultry for about 20 percent. The cattle and hog sectors each account for about 30 percent, with the amount fed to cattle peaking in the liquidation phase of the cycle in 1986/87 and 1987/88. Total corn used by livestock also peaks in these two years at 109 and 111 MMT, respectively. Hog corn use is fairly stable at around 33 MMT annually, so fluctuation in total feed use of corn is generally

Figure 10   Projected corn and cattle prices



attributable to the beef cattle sector. This movement is explained by two factors. First is the underlying influence of the cattle cycle which determines feeder cattle availability and thus corn demand by feedlots. Second is the flexibility cattle feeders have in responding to corn price changes in the short run (within a year). Higher corn prices can mean that cattle are fed to lighter finished weights than would be the case with lower prices, so less corn is consumed per finished animal. These weights also respond to movements in fed beef cattle price. In the projection, sharp increases in corn price in 1985/86 and 1989/90 reduce fed beef average liveweights to 1077 and 1063 pounds, respectively, in contrast with the other years' average of 1143 pounds.

These livestock feed use patterns are quite similar to those of the 1970s, as is to be expected since beef and pork production, which together use about two-thirds of feed corn, remain fairly constant. If the projected increases in broiler production are also accompanied by improvements in feeding efficiency, as in the past, corn use by poultry may be even less than anticipated by these results. Overall, livestock feed use of corn declines as a proportion of total disappearance, although it remains the major category. During the period 1975/76 to 1979/80 feed use of corn average about 61 percent of disappearance (less stocks); over the 1980s, the average is 55 percent. In the absolute, annual corn feed use does not change drastically, averaging 99 MMT in the 1970s and 104 MMT in the 1980s.

Given that although feed use increases in absolute terms it declines in relative importance, what happens to other categories of corn use in the 1980s? Food, seed, and industrial use of corn almost doubles over the decade; 29 MMT are utilized in 1989/90, accounting for 13 percent of disappearance versus nine percent in 1980/81. This projection does not explicitly account for any major expansion in production of ethanol and/or high fructose sweeteners from corn. With a slowdown in OPEC oil price increases, the outlook for gasohol does not appear very bright. In November 1981, the president of Archer Daniel Midland Foods suggested that more gasohol could be sold if it were identified as super unleaded with ethanol, to emphasize its higher octane level. This pitch rather lamely tries to justify the current price premium paid for gasohol over regular unleaded. In the absence of government subsidies, such a campaign can probably not sustain gasohol sales; only relative price changes in its favor will do that. While a large corn processing sector would have appreciable impact on the market, one is not forthcoming in the forseeable future.

United States exports of corn over the next ten years fluctuate between 27 and 37 percent of disappearance, not counting the projected 44 percent in the last year of the decade when there are massive Soviet imports. Between 46 and 74 MMT are exported annually from the US, whose exports average 75 percent of world exports. Thus, exports are rather more important than they were in the 1970s, when they averaged about 30 percent or less of disappearance.

In the world market, the Soviet Union's imports are as much as 21 percent of total imports in two years and 29 percent in 1989/90, the disasterous production year. Otherwise, Soviet imports account on the average for 10 to 15 percent of the total. Imports by the rest of the world increase from 64 MMT in 1980/81 to 85 MMT in 1979/80. Within this subtotal, relative market shares of the remaining exporters change over the ten year period. The Group I countries (Japan, Malaysia, Taiwan, South Korea, Mexico, Egypt, Israel) import 27 percent of the subtotal in 1980/81 and increase to 38 percent in 1989/90. This gain is at the expense of the European Community, whose share falls from 29 to 26 percent over the same period, and the rest of the world, whose proportion declines from 22 to 16 percent. Eastern Europe and the Group IV countries (Spain, Portugal, Greece, and Canada) maintain fairly constant shares of seven and 14 percent, respectively. In absolute terms, Group I almost doubles its imports from 17 to 32 MMT annually, while the EC's increase only 4 MMT, to 22 MMT at the end of the decade. Eastern European countries import only 5 MMT in 1989/90 and Group IV about 12 MMT the same year. Imports by all other countries are set equal to 14 MMT annually through the forecast period.

Average total world corn trade volume in the eighties is 85 MMT annually, compared with 55 MMT in the seventies, and 24 MMT in the sixties. It should be noted that since all other countries' exports remain at about 20 MMT annually, fluctuations are absorbed by the United States as the residual supplier. The exogenous specifications of the exports of these other nations ensures there willbeno response toprice changes over the forecast period. While this is an unrealistic assumption, it does seem reasonable to expect that their supply response will be rather limited by domestic production constraints. Consequently, they will probably not be able to increase their average market share much beyond the 25 percent implied by the forecast.

Annual ending (September 30) stocks over the decade of the eighties are projected to average about 40 MMT, representing carry-in equal to about 22 percent of the year's use. These stocks do not fall below 30 MMT at any time during the decade. This situation is in contrast to that of the seventies, when stocks fluctuated greatly and averaged about 20 MMT annually, with a carry-in stocks to use ratio of about 90 percent. In the sixties, the average carry-in was 32 MMT, a stocks to use ratio of 80 percent. Of all the projections of the simulation, that of stocks is most subject to error for several reasons. First, the loan rate may be overstated, implying a systematically larger buildup than would otherwise occur and thus a higher corn price. Second, as a source of residual supply, stocks will be drawn down to cover unforeseen needs precipitated by random events such as short crops due to poor weather. (Note that here US production has been assumed to stay exactly on trend, an unlikely sequence of events.) Consequently, stocks could be expected to be lower than forecast. On the other hand, increasing US production and fairly stable US consumption implies a less tight market than in the 1970s despite increases in exports. Then, it would not be unrealistic to expect larger stocks than those of the past ten years. One interesting aspect of the predicted outcome is that these fairly high stock levels appear to have no great stabilizing effect on corn price. However, this may be attributable to the overestimated loan rate as well as to the over-riding role of the residual export market in determining price.

US production is projected to increase smoothly from 166 MMT in 1980/81 (actual was 168 MMT) to 212 MMT ten years later. The 1980s average is 190 MMT, versus the 1970s 150 MMT, a figure influenced by several small crops. Area planted is forecast to average around 31 million hectares, compared with 28 million over the previous two decades, with a maximum of 32 million in 1986/87 and a minimum of 30 in 1982/83). Yields increase from 6.3 to 8 MT per hectare, the equivalent of a rise from 100 to 127 bushels per acre. The model predicted area planted would be 31 million hectares in 1980/81 and 1981/82; actual figures were 34 million hectares in each year. Yield was predicted to be 6.3 MT per hectare (100 bushels per acre) in 1980/81 and was actually 5.7 MT (91 bushels). In 1981/82, yield was forecast to be 6.5 metric tons (103 bushels) but turned out to be 6.8 (109 bushels). As a result of these differences (and also those in area harvested), production was slightly underpredicted in 1980/81 (166 versus 168 MMT actual) and greatly underpredicted in 1981/82 (171 MMT versus 205 actual). These discrepancies illustrate the difficulty of predicting weather and its influence on crops.

Limitations

As discussed above, the results of this analysis understate potential instability in the market. Surely more than just Soviet corn imports will fluctuate in a stochastic fashion over the decade. However, the findings are useful as a basis for comparison with future Monte Carlo experiments as well as with predictions of other similar models.

Several caveats about the likely accuracy of these predictions should be mentioned. Forecast error can arise from several sources. As outlined by Pindyck and Rubinfeld, they are as follows.

1. The regression equation contains an implicit additive error term.
2. The estimated values of the coefficients of the equation are themselves random variables and will therefore differ from the true values.
3. The exogenous variables may have to be forecasted themselves, and these forecasts may contain errors.
4. The equation itself may be misspecified; i.e., the functional form may not be representative of the real world.

(p. 360)

The stochastic simulation here performed is susceptible to error from all these sources, but the direction or magnitude of any error is impossible to predict with any certainty, although some general speculation can be attempted.

The results here represent, in a sense, the best of all possible worlds in which most variables behave in a stable, non-erratic manner. Some likely sources of instability which would greatly influence the results can be identified. For one, the projections of US production may be too high if average yield does not continue to increase (as is assumed in the projection). In that case, it is likely that corn supplies will be somewhat tighter and corn price perhaps higher, although magnitudes cannot be predicted. The assumption of stable, on trend US production is crucial to the results, since the US produces more than one-half of the corn grown in the world.

Another likely source of instability lies in the behavior of other countries which import corn. While the equations which are used to describe and predict their behavior do not (except for Eastern Europe) contain corn price as an argument, there is probably some longer-run price adjustment response which could be expected if corn price became vary high or very unstable. Furthermore, internal policies and conditions in these countries might change and thus alter their feedgrain needs and import demands. The bloc countries of Eastern Europe are particularly unpredictable in this respect. The importance of the export market in determining corn price means that inaccuracies in forecasting other nations' corn demand could have an appreciable impact on the expected corn price level and instability.

SUMMARY AND CONCLUSIONS

Summary

The US is the major supplier to the international corn market, which is characterized by price inelastic demand. On the average over the past decade, one-third of annual US corn production has been exported, an amount which represents three-fourths of world corn trade. The import behavior of the Soviet Union has been a source of shocks to the corn market. Unstable domestic feedgrain production coupled with a commitment to a stable livestock supply has resulted in sporadic, large purchases of corn on the world market. In 1975/76, unprecedented Soviet imports of 12 MMT represented 20 percent of world corn trade or eight percent of US production. Corn price instability during the 1970s was marked. In the absence of significant price responsiveness elsewhere in the world market, adjustment to these disruptions has occurred in the domestic US economy.

A structural econometric model of the US domestic corn/livestock and corn export markets is used to investigate the nature of adjustment to market shocks originating in USSR corn import behavior. The model is well suited to such an analysis due to the degree of disaggregation of the various market sectors. In particular, the specification of derived corn demand by livestock category rather than in the aggregate allows the possibility of differential sectoral response to changes in corn price.

Sixty percent of annual US corn production is fed to livestock. Cyclical movement in hog and beef cattle production (the main users of corn) has resulted in corresponding cyclical movement in derived corn feed demand. The significance of the cyclical movement is that price responsive corn demand in the hog and cattle sectors is most inelastic when animal numbers are highest. Consequently, market shocks during these periods cause large corn price gyrations in percentage terms, which feed back into cycles through their effects on production and inventory decisions. While the phase of the cycles is not expected to change appreciably when shocks occur, the amplitude of the cycles may be affected as producers make short-run adjustments in output and feed use. Therefore market response to shocks will depend on their timing and sequence as well as their magnitude.

The structural model contains 53 equations, of which 35 explain behavioral relationships. Hog, fed and nonfed beef cattle, and broiler production are endogenous as are wholesale product prices. The demand for feed corn is derived from these livestock production levels. Stocks and other domestic disappearance, as well as US corn production, are also determined within the model. The demand for corn on the world market is composed of a set of demand estimates for groups of importers, aggregated according to their similar importing characteristics. The US is set as the residual supplier to the world market; corn exports by other countries are exogenous. Equilibrium corn price is determined endogenously when the world market clears.

Estimated over the corn crop years 1961/62 to 1978/79, the dynamic, nonlinear (in variables) model is annual in period, except for the hog production sector, which is semiannual. All equations in the model were estimated by ordinary or generalized least squares. Results were judged satisfactory based on standard errors of the coefficients, expected signs, goodness of fit, and turning point accuracy. Validation by historical simulation demonstrated the model's ability to track well; the average percentage root mean square error for the 53 endogenous variables was 12 percent.

To gauge the effects of erratic Soviet import behavior and the paths of key variables over the 1980s, the deterministic paths of the exogenous variables were projected over the period. The model was solved with the only source of stochastic fluctuation Soviet corn import behavior. The projections show that if large Soviet imports occur at the next expected peak of the cattle cycle at mid-decade, corn price increases more strongly than if they occur at the start of the buildup phase in the early 1980s. Cyclical price movement still continues in the beef cattle and hog sectors; the brunt of the instability in corn price is felt by feeder cattle producers. In general, US livestock production remains at the per capita levels of the 1970s, with the exception of broiler consumption which doubles over the decade.

Conclusions

The conclusions which follow from the empirical analysis of the US corn/livestock and corn export markets have implications for the conduct of American agricultural policy in the decade ahead. After a review of the major findings of the study, their significance for stabilization policies is discussed.

Assuming the econometric model is correctly specified, volatile Soviet corn imports are reflected in instability in world price, which is also the US price, of corn. The domestic US market for corn is unprotected from price swings in the international market. There is virtually no short-run price response on the part of other world market participants, whose internal markets are often insulated from world conditions through government trade and/or support policies. Adjustment to disruptions, such as those caused by the Soviets, occurs with the US domestic economy.

In the US, neither food, seed, and industrial use nor stocks have exhibited the capability to absorb or buffer shocks. The former has shown little responsiveness to changes in corn price, most likely because there are few substitutes for corn in these activities. Stocks have not overhung the corn market as in the wheat market; total corn carryover was an average of only 13 percent of production over the past decade, in contrast to 46 percent for wheat. Government-controlled stocks have been small and were zero from 1973/74 through 1976/77. Consequently, adequate stocks were not available for release at times of peak demand and/or reduced supply. As for production, the elasticity of area planted with respect to corn price is only 0.12 at the sample means.

Within the livestock sector, the poultry and dairy industries have exhibited little corn price responsiveness. For poultry, the price elasticity of demand is -0.15 at sample means. For dairy, the elasticity of corn fed to beef with respect to corn price is -1.6 at sample means. For pork production, the short run (six month) elasticity is approximately zero; but one year later, after the size of the pig crop has been adjusted, the elasticity of corn use with respect to lagged corn price is -2.1 at sample means. Thus, as the most price responsive sectors, hogs and beef cattle have borne the brunt of adjustment to corn market shocks.

The role of the US as the residual supplier to a residual world market exacerbates the adjustment problems faced by the US livestock sector, primarily in beef cattle and hogs. The price of corn will be determined and bid up at the margin by fluctuating foreign demand. The problem of sharp increases in corn price in response to destabilizing events is felt most acutely when livestock production in the main corn-consuming sectors is at its cyclical peak. At this point, derived demand for feed corn is most inelastic as animal numbers are at their highest. At the peak of the cattle cycle, the elasticity of corn use with respect to corn price -0.95; at the cycle's trough, the same elasticity is -1.95, both compared to the mean value of -1.6 at the sample means. In the hog sector at the top of the cycle, the elasticity of corn use with respect to lagged corn price is -1.1, compared to -2.7 at the trough and -2.1 at sample means. With only limited opportunity for short-run adjustment in the aggregated market, inelastic domestic corn demand, combined with inelastic annual supply, results in disproportionate price movements when one or the other of the curves shifts randomly.

The effects of corn price instability are not felt evenly among US livestock producers. In particular, cow-calf producers in the beef sector absorb a large part of the fluctuation. The price of feeder cattle is determined in feedlot operators' bidding for the fixed annual supply. The operators' willingness to pay depends upon their assessment of the profitability of feeding cattle as determined by the relationship between fed cattle prices and input costs, most notably the price of corn. When corn price increases, feeder cattle prices fall while fed beef cattle prices remain more stable (due to the presence of substitutes on the demand side). Similarly, Freebairn and Rausser found that drops in beef prices (due to an increase in imports) "place a heavier burden on cattle breeders relative to cattle feeders" (p. 688). Low returns to cow-calf producers depress the value of their ranch land, for which there are few alternative uses. The hog sector is less affected by this problem because of the number of operations which produce hogs and corn simultaneously, providing a hedge against very high or very low grain prices.

Consumers feel the effects of corn price instability to the extent that it is reflected in livestock product prices but also through changes in the quantity and quality of supplies. Longer term cyclical movement in production produces variation in availability (mirrored in price movements). For example, per capita pork consumption at the cycle peak has been as much as 20 percent greater than at the trough. Superimposed on these patterns are shorter run movements which may be attributable to changes in corn price. In the beef sector, corn price affects total beef production through the slaughter mix of fed versus nonfed beef (more of the latter when corn price is high) and through the final weight of the feedlot animal. So, hamburger may be more or less abundant relative to sirloin steak depending on the stage of the output cycle and the current price of corn. In both hog and cattle raising, corn price instability may limit expansion in buildup phases or hasten liquidation in downswings.

US agricultural policy has in the past dealt with the livestock, grain, and export sectors separately, if at all. The results of this analysis of instability have implications for the efficacy of any future stabilization policy. The presence of combined livestock/grain operations on many farms and the relative unimportance of exports led to a policy that focussed on maintaining producers' incomes through the use of nonrecourse loans and area restrictions. However, the structure of livestock production has moved toward concentration in large industrialized operations, particularly in beef cattle and poultry. As Gustafson points out, "They operate on profit margins defined by the differences in input and product prices" (p. 128) and no longer have the options to sell grain directly or indirectly through its conversion to livestock product. At the same time, exports of corn have become an increasingly important component of the market and of the agricultural economy. Given these changed circumstances and the likely continuation of volatile Soviet import behavior, corn price instability will affect a different and larger set of interests than in the past.

Traditionally, cattle and hog producers have resisted government intervention in the form of price supports since they objected to the imposition of limitations on output. Institution of supply controls would incidentally raise the question of whether cyclical movement could be suppressed in pursuit of stability. Given the disagreement over the nature of the cycle-motivating force, this would make an interesting policy experiment. However, as Breimyer and Rhodes point out, there is a mutuality of interest between corn and livestock producers in terms of output stability.

> An operative price policy might also stabilize the demand for feedgrains and thereby reduce shocks on grain producers, feed manufacturers, and government program operations. What we have in mind is the weak market that a bumper crop of corn may face in the fall of 1975 due to hog producers' having sold off so much of their stocks.
>
> (p. 946)

To the extent that corn price instability today influences livestock inventory decisions, future corn feed use is also affected.

US corn production has had a rather stable upward trend over the past 20 years, save for weather and one incidence of disease, which could not be controlled, anyway. In this respect, stabilization policy in the grain sector focusses on reserve management. Past levels of stocks were accumulated as a byproduct of support programs, without regard for their adequacy in times of short supply. As it turned out, levels of corn stocks were not sufficient to provide a buffer against the destabilizing events of the 1970s. Now, the government may impose a ceiling of not less than 25 MMT on the feedgrain accumulated in the farmer owned reserve (FOR). While this minimum figure represents only about four percent of 1981/82 world feedgrain use and 13 percent of US use, the FOR's design may make it more responsive to price changes and thus a better buffer. In particular, the corn price release level is set with regard to corn users as well as corn suppliers, a departure from previous practice. However, the simulation results showed that a stock level almost 40 percent larger than the 25 MMT minimum would not provide significant price stability if the Soviet's imports continue to be large and erratic. Furthermore, these use percentages are no greater than those which prevailed in the 1970s, when price instability was marked.

The implication is that reserve management must consider sufficiency as a criteria for stock accumulation and that, currently, the minimum target is set too low by standards of past experience. Breimyer and Rhodes state,

> It is unlikely that large and short crops of feed grains in the United States will be matched by strong and weak world demand. Thus, US reserves are the prerequisite bridge to capitalizing on variable world demand.
>
> (p. 947)

Their statement implies that not only sufficiency to stabilize price should be a goal of reserve management but also to increase revenue when market demand is strong. However, a less ambitious policy would settle on the first objective.

As long as other countries eschew internal adjustment to market shocks, the US as the largest and the residual supplier will end up trying to stabilize the world market through its domestic programs. Past instability has raised concerns among corn importers which transcend price considerations. Reliability of supply, particularly for nonproducers such as Japan, may be of paramount importance, for unreliability of grain supply implies the possibility of distress livestock slaughter. The imposition of the grain embargo on the USSR did nothing to enhance the US image on this score. Nonetheless, bilateral agreements may assure traditional and valued customers of supply in tumultuous times. Currently, the bilateral agreement with the unpredictable Soviet Union has probably acted to stabilize world price since its consultative requirement provides the market with advance notice of Soviet intentions. It should be noted that these agreements may increase instability in the remaining residual market as supply inelasticity is increased.

For the United States, the basic problem in formulating corn trade and also domestic policy is its inability to force other nations to help bear the burden of adjustment to market shocks. The Soviet Union is, of course, a prime example of intransigence. But allies would also resist such adjustment. In particular, the EC depends on its Common Agricultural Policy, which insulates its internal grain markets, to help hold the coalition together. Faced with the likely uncooperative nature of corn trading partners, the US may have to consider unilateral export controls in years when the domestic crop is short or demand high (as at livestock cycle peaks). US agricultural trade policy should aim to avoid market shocks during years of peak domestic corn demand.

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