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Functional form in the supply of broilers and its irreversibility

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FUNCTIONAL FORM IN THE SUPPLY OF BROILERS AND ITS IRREVERSIBILITY

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I. INTRODUCTION

The main purpose of the study presented in this dissertation is the construction of an econometric model to explain supply functions of agricultural products. This study will, in general, attempt to contribute to the fund of knowledge concerning the influence of prices and technology on agricultural products in the United States. Improved supply analysis can provide a basic contribution to the development of important related research areas. As an example, the development of the analysis of technological change will depend largely on supply analysis. Therefore, the objects of this study on agricultural supply are:

1. to understand the mechanisms of supply response,
2. to forecast supply change, and
3. to prescribe solutions to problems related to agricultural supply.

All of these are important both at the individual farm level and at the decision-making level.

The analysis of aggregate supply has been necessitated because of problems which agriculture faces in adjusting supplies to market demand. The concept of aggregate supply is particularly important in agriculture both for policy analysis and for forecasting. A knowledge of how aggregate output is likely to change with respect to a change in average price of farm products is of interest in order to forecast the consequences of a change in farm price policy. A knowledge of change in aggregate supply is necessary in order to predict farm income since the average price of farm products is determined largely by a shift in aggregate supply relative to demand over time. However, there are difficulties in matching the growth of aggregate supply with aggregate demand. For this reason, most countries have one of two problems: (1) a surplus and relatively low prices for farm products or (2) a deficit problem and relatively high prices for farm products. As an example, the United States has needed a greater understanding of supply phenomena in order to control surpluses and to raise farm prices and incomes. Lesser developed countries have needed to understand supply phenomena in order to increase output levels enough to insure adequate human nutrition and larger populations. This is why problems of supply have long been a dominant issue in agriculture and answers to agriculture's major problems rest on supply response.

Farmers have considerable opportunities for substitution of one commodity for another in production over a long period of time. Essentially, this leads to adjustments among products until comparable resources earn similar rates of return in the production of each commodity. Public policy, concerned with the return of farm resources and farm income, must consider the output response of farm output to changing economic conditions, based on this improved knowledge. Therefore, the elasticity parameter for supply functions is important for public policy because it measures the producers' ability to adjust production to changing economic conditions.

As noted above, improved knowledge of product supply of farm output is useful in formulating policies towards greater stability of the economy of the agricultural sector, and is useful in helping farmers formulate better decisions on investment and planning. This knowledge is also useful for investment planning by firms producing inputs used by the agricultural sector.

Given the value of improved knowledge of supply, numerous attempts have been made to estimate supply functions of agricultural products during the last three decades, but few studies have undertaken the estimation of supply functions of the broiler industry.

A. Broiler Industry in the United States

A broiler is a young chicken usually of 7 to 10 weeks of age. Commercial broiler production was started in the 1920s. At an early stage, broilers were produced by numerous small farms throughout the country. Today, most of the broilers are produced (by contract growers) in specific regions of the country. The broiler industry is highly specialized and integrated vertically and/or horizontally.

Broiler products have become more important in terms of consumption and production. Table 1.1 shows the trend of per capita consumption of meat in retail weight for the period 1960-1980. The consumption of beef has increased from 64.2 pounds in 1960 to 76.5 pounds in 1980, showing a 18 percent increase. Consumption was 94.4 pounds in 1976, having increased about 47 percent from 1960. The per capita consumption of pork has been relatively stable around 60 pounds over the last two decades. Broiler consumption has sharply increased by about 105 percent from 23.4 pounds in 1960 to 48 pounds in 1980. Consumption of turkey has also

Table 1.1. Per capita consumption of meat in retail weight:[a] 1960-1980[b]

Year	Red meat					Poultry			Grand
	Beef	Veal	Pork	Lamb/mutton	Total	Broiler	Turkey	Total	total
60	64.2	5.2	60.3	4.3	134.0	23.4	6.1	29.5	163.5
61	65.8	4.7	57.7	4.5	132.7	25.8	7.4	33.2	165.9
62	66.2	4.6	59.1	4.6	134.5	25.7	7.0	32.7	167.2
63	69.9	4.1	61.0	4.4	139.4	27.0	6.8	33.8	173.2
64	73.9	4.3	61.0	3.7	142.9	27.6	7.4	35.0	177.9
65	73.6	4.3	54.7	3.3	135.9	29.5	7.5	37.0	172.9
66	77.0	3.8	54.4	3.6	138.8	32.3	7.8	40.1	178.9
67	78.8	3.2	60.0	3.5	145.5	32.8	8.6	41.4	186.9
68	81.2	3.0	61.4	3.3	148.9	33.1	7.9	41.0	189.9
69	82.0	2.7	60.5	3.1	148.3	35.2	8.3	43.5	191.8
70	84.1	2.4	61.9	2.9	151.3	36.9	8.0	44.9	196.2
71	83.4	2.2	68.0	2.8	156.4	36.7	8.3	45.0	201.4
72	85.5	1.8	62.6	2.9	152.8	38.4	8.9	47.3	200.1
73	80.5	1.5	57.1	2.4	141.5	37.4	8.5	45.9	187.4
74	85.6	1.9	61.7	2.0	151.2	37.5	8.9	46.4	197.6
75	87.9	3.4	50.6	1.8	143.7	37.2	8.6	45.8	189.5
76	94.4	3.3	53.7	1.6	153.0	40.4	9.2	49.6	202.6
77	91.8	3.2	55.8	1.5	152.3	41.7	9.3	51.0	203.3
78	87.2	2.4	55.9	1.4	146.9	44.5	9.3	53.8	200.7
79	78.1	1.7	63.8	1.3	144.9	48.6	10.1	58.7	203.6
80	76.5	1.5	68.3	1.3	147.6	48.0	10.6	58.6	206.2

[a]Consumption of meat expressed in lbs.

[b]Source: 1) Poultry & Egg Situation, PES - 267 and 310, USDA (56).
2) Food Consumption, Prices, and Expenditures, 1960-1980, Statistical Bulletin No. 672, USDA (55).

rapidly increased from 6.1 pounds to 10.6 pounds, showing a 74 percent increase.

Total consumption of red meat has increased about 10 percent during 1960-1980, while poultry consumption[1] (here broiler plus turkey only) has increased about 100 percent for the same period. Total meat consumption has increased about 24 percent. Therefore, it can be concluded that the increase in meat consumption depends largely on the increase in broiler meat consumption, because total meat consumption has increased by about 40 pounds and broiler meat consumption by about 25 pounds over the last two decades.

Table 1.2 shows the relative portion of each meat over total meat consumption. The relative portion of beef consumption was about 40 percent in 1960, and 37 percent in 1980 of the total meat consumption, peaking at 47 percent in 1976. The relative share of pork consumption was 37 percent in 1960, and 33 percent in 1980, dropping down to 26.5 percent in 1976. The relative share of broiler consumption has continuously increased from 14 percent in 1960 to 23.3 percent in 1980. The relative share of total red meat consumption has continuously decreased from 82 percent in 1960 to 71.6 percent in 1980, while poultry's share has continuously increased from 18 percent to 28.4 percent during the same period. Thus, the consumption pattern of meat has been gradually toward poultry products during the last two decades. Since more than 80 percent

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[1]For more accuracy, consumption of mature chickens, ducks, and other poultry products should be included. However, their share is relatively small, compared with broiler consumption.

Table 1.2. Relative share[a] of per capita consumption of meat: 1960-1980

Yr.	Beef	Veal	Pork	Lamb/mutton	Total	Broiler	Turkey	Total	Grand total
60	39.3	3.2	36.9	2.6	82.0	14.3	3.7	18.0	100
61	39.7	2.8	34.8	2.7	80.0	15.6	4.4	20.0	100
62	39.6	2.8	35.3	2.7	80.4	15.4	4.2	19.6	100
63	40.4	2.4	35.2	2.5	80.5	15.6	3.9	19.5	100
64	41.5	2.4	34.3	2.1	80.3	15.5	4.2	19.7	100
65	42.6	2.5	31.6	1.9	78.6	17.1	4.3	21.4	100
66	43.0	2.1	30.4	2.1	77.6	18.1	4.3	22.4	100
67	42.2	1.7	32.1	1.8	77.8	17.6	4.6	22.2	100
68	42.8	1.6	32.3	1.7	78.4	17.4	4.2	21.6	100
69	42.8	1.4	31.5	1.6	77.3	18.4	4.3	22.7	100
70	42.9	1.2	31.5	1.5	77.1	18.8	4.1	22.9	100
71	41.4	1.1	33.8	1.4	77.7	18.2	4.1	22.3	100
72	42.7	0.9	31.3	1.5	76.4	19.2	4.4	23.6	100
73	42.9	0.8	30.5	1.3	75.5	20.0	4.5	24.5	100
74	43.3	1.0	31.2	1.0	76.5	19.0	4.5	23.5	100
75	46.4	1.8	26.7	0.9	75.8	19.6	4.6	24.2	100
76	46.6	1.6	26.5	0.8	75.5	19.9	4.6	24.5	100
77	45.2	1.6	27.4	0.7	74.9	20.5	4.6	25.1	100
78	43.4	1.2	27.9	0.7	73.2	22.2	4.6	26.8	100
79	38.4	0.8	31.3	0.7	71.2	23.8	5.0	28.8	100
80	37.1	0.7	33.2	0.6	71.6	23.3	5.1	28.4	100

[a]Relative share of consumption expressed in percentages.

of poultry consumption is from broilers, broiler products have become more and more important from the view of consumption.

Together with a rapid increase in per capita consumption of broiler products, broiler production has also sharply increased during the same period. Table 1.3 shows the production trends of various meats for 1960-1980. Beef production increased continuously from 1960 to 1976, peaking at 26 billion pounds in carcass weight in 1976, then trended downward from 1977 to 1980. Pork consumption, compared with beef production, has been relatively stable for the same period. However, veal, lamb and mutton production has been decreasing. Total red meat production has increased by about 27.6 percent from 30.5 billion pounds in carcass weight in 1960 to 39.0 billion pounds in 1980. However, poultry production has experienced a very high increase, showing about a 189 percent increase from 6.3 billion pounds in liveweight in 1960 to 18.2 billion pounds in 1980. Broiler production has increased from 5.1 billion pounds in liveweight in 1960 to 15.3 billion pounds in 1980, while turkey production increased from 1.1 billion pounds in 1960 to 2.9 billion pounds in liveweight in 1980. Total meat production has increased at about 20.3 billion pounds from 36.9 million pounds in 1960 to 57.2 billion pounds in 1980.

Table 1.4 shows the relative share of each meat over total meat production. The relative share of beef production was about 40 percent in 1960, and about 38 percent in 1980, peaking at about 48 percent in 1975. Pork's share seems to be decreasing, from 37.7 percent in 1960 to 29.1

Table 1.3. Meat production:[a] 1960-1980[b]

Yr.	Red meat (carcass weight) Beef	Veal	Pork	Lamb/mutton	Total	Poultry (liveweight) Broiler	Turkey	Total	Grand total
60	14,753	1,109	13,905	768	30,535	5,136	1,190	6,326	36,861
61	15,327	1,044	13,648	832	30,851	5,924	1,581	7,505	38,356
62	15,324	1,015	13,953	808	31,100	6,028	1,379	7,407	38,507
63	16,456	929	14,493	770	32,648	6,361	1,460	7,821	40,469
64	18,456	1,013	14,598	715	34,782	6,647	1,572	8,219	43,001
65	18,727	1,020	12,781	651	33,179	7,175	1,669	8,844	42,023
66	19,726	910	12,798	650	34,084	7,826	1,860	9,686	43,770
67	20,219	792	14,131	646	35,788	8,229	2,096	10,325	46,113
68	20,880	734	14,515	602	36,731	8,311	1,832	10,143	46,874
69	21,158	673	14,245	550	36,626	9,064	1,807	10,871	47,497
70	21,685	588	14,699	551	37,523	10,073	1,988	12,061	49,584
71	21,902	546	16,006	555	39,009	10,224	2,086	12,310	51,319
72	22,419	459	14,422	543	37,843	10,958	2,279	13,237	51,080
73	21,277	357	13,223	514	35,371	10,859	2,266	13,125	48,496
74	23,138	486	14,331	465	38,420	11,000	2,326	13,326	51,746
75	23,976	873	11,779	410	37,038	10,982	2,163	13,145	50,183
76	25,969	853	12,688	371	39,881	12,408	2,463	14,871	54,752
77	25,279	834	13,247	351	39,711	12,741	2,392	15,133	54,844
78	24,242	632	13,393	309	38,576	13,656	2,503	16,159	54,735
79	21,446	434	15,450	293	37,623	15,111	2,748	17,859	55,482
80	21,644	400	16,615	318	38,977	15,277	2,908	18,185	57,162

[a]Production expressed in million pounds.

[b]Source: 1) For red meats: Food Consumption, Prices and Expenditures, 1960-80, Statistical Bulletin No. 672, USDA (55).

2) For broilers and turkey: Poultry and Egg Statistics through 1972 -- Statistical Bulletin No. 525, USDA (57), and supplement for 1972-1975 to Statistical Bulletin No. 525, USDA (58), PES-301 and 309, USDA (56).

Table 1.4. Relative share[a] of meat production: 1960-1980

Yr.	Red meat: Beef	Red meat: Veal	Red meat: Pork	Red meat: Lamb/mutton	Red meat: Total	Poultry: Broiler	Poultry: Turkey	Poultry: Total	Grand total
60	40.0	3.0	37.7	2.1	82.8	14.0	3.2	17.2	100
61	40.0	2.7	35.6	2.1	80.4	15.4	4.2	19.6	100
62	39.8	2.6	36.2	2.2	80.8	15.2	3.5	19.2	100
63	40.7	2.3	35.8	1.9	80.7	15.7	3.6	19.3	100
64	42.9	2.4	33.9	1.7	80.9	15.5	3.6	19.1	100
65	44.6	2.4	30.4	1.6	79.0	17.1	3.9	21.0	100
66	45.1	2.1	29.2	1.5	77.9	17.9	4.2	22.1	100
67	43.9	1.7	30.6	1.4	77.6	17.8	4.6	22.4	100
68	44.5	1.6	31.0	1.3	78.4	17.7	3.9	21.6	100
69	44.5	1.4	30.0	1.2	77.1	19.1	3.8	22.9	100
70	43.8	1.2	29.6	1.1	75.7	20.3	4.0	24.3	100
71	42.7	1.0	31.2	1.1	76.0	19.9	4.1	24.0	100
72	43.9	0.9	28.2	1.1	74.1	21.5	4.4	25.9	100
73	43.9	0.7	27.3	1.0	72.9	22.4	4.7	27.1	100
74	44.7	0.9	27.7	0.9	74.2	21.3	4.5	25.8	100
75	47.8	1.7	23.5	0.8	73.8	21.9	4.3	26.2	100
76	47.4	1.5	23.2	0.7	72.8	22.7	4.5	27.2	100
77	46.1	1.5	24.2	0.6	72.4	23.2	4.4	27.6	100
78	44.3	1.1	24.5	0.6	70.5	24.9	4.6	29.5	100
79	38.7	0.8	27.8	0.5	67.8	27.2	5.0	32.2	100
80	37.9	0.7	29.1	0.5	68.2	26.7	5.1	31.8	100

[a]Relative share of production expressed in percentage.

percent in 1980, dropping down to 23.2 percent in 1976. The share of broiler production has had an upward trend from 14 percent in 1960 to 26.7 percent in 1980. It should be noted that the share of broiler production matched that of pork production in 1976, and that their shares were at about the same level for about four years (1976-1979). The share of total red meat production versus that of poultry production has gradually been changed from 83 percent versus 17 percent in 1960 to 68 percent versus 32 percent in 1980. Thus, production pattern of meat has gradually been toward poultry products during the last two decades. Since more than 80 percent of poultry production comes from the broilers, broiler products have also become more and more important from the view of production.

Table 1.5 shows annual growth rates of per capita consumption and production of various meats. The growth rates are estimated[1], based on the data shown in Tables 1.1 and 1.3. Annual growth rates of beef and pork for per capita consumption are 1.4 percent and 0.06 percent, respectively. Veal, lamb and mutton for consumption have experienced a

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[1]For estimation of growth rates: $Q_t = Q_o(1 + g)^t = Q_o B^t$ is used, where: g = growth rate, and $B = 1 + g$

By taking the logarithms on both sides $\log Q_t = \log Q_o + t \log B$

$$= \alpha + \beta t,$$

where: $\beta = \log B$

Therefore, $g = B - 1 = e^{\hat{\beta}} - 1$

Table 1.5. Annual growth rates of consumption and production of meats: 1960-1980

	Consumption	Production
Beef	1.4%	2.3%
Veal	-4.8%	-3.9%
Pork	0.06%	0.14%
Lamb/mutton	-6.5%	-5%
Total of red meat	0.54%	1.2%
Broiler	3.3%	5.3%
Turkey	2%	3.7%
Total poultry	3.1%	5%
Grand total	1.1%	2.1%

negative growth rate. Growth rates of broiler and turkey for consumption are 3.3 percent and 2 percent, respectively. Growth rates of poultry consumption are 6 times higher than that of red meat consumption. Growth rates of total meat consumption are 1.1 percent over the last 21 years. Growth rate of broiler consumption is the highest among various meats over the last 21 years.

Output growth rates of beef and pork are 2.3 percent and 0.14 percent, respectively. Growth rates of pork in consumption and production are negligible, showing less than 0.2 percent in both cases. Growth rates of veal, lamb and mutton have been negative. Broilers and turkeys have 5.3 percent and 3.7 percent growth rates, respectively. Growth rates of poultry production are 4 times higher than that of red meat production. The annual growth rate of total red meat has been 2.1 percent over the last 21 years. Broilers have the highest growth rate over the same period. To conclude, the broiler industry has experienced the highest growth rate in both per capita consumption and production.

Since this study is related to supply analysis of the broiler industry, focus will be placed on the production side. As discussed earlier, the broiler industry has experienced a remarkable growth in its production, and its growth rate of production has dominated the growth of all other meats. Then, the question may be posed, "What brought about the rapid growth of broiler production?" The answer can be made by borrowing from traditional microeconomic theory. An increase in output can be explained by (1) an increase in output price and (2) a decrease in production cost. An increase in product price gives producers an incentive to produce more. However, as in Table 1.6, the broiler price at farm level fell for 1955-72 when output increased sharply. The broiler price seemed to trend downward rather than upward over the period of 1955 to 1976. The downward trend of broiler price and the sharply upward trend of output violate the normal assumption of relationships between output supplied (or produced) and output price. Therefore, it may be difficult to explain the rapid growth of broiler production by the positive relationship between output and product price,

Table 1.6. Farm price and production cost of broilers in cents per pound in liveweight: 1955-1976[a]

Year	Price	Cost	Feed
1955	25.2	20.5	13.1
1956	19.6	19.0	12.3
1957	18.9	18.2	11.9
1958	18.5	17.6	11.6
1959	16.1	16.7	11.0
1960	16.9	15.7	10.3
1961	13.9	15.1	10.0
1962	15.2	14.8	9.9
1963	14.6	14.8	10.1
1964	14.2	14.5	10.0
1965	15.0	14.5	9.8
1966	15.3	14.7	9.8
1967	13.3	14.1	9.1
1968	14.2	13.5	8.4
1969	15.2	13.8	8.5
1970	13.5	14.2	8.8
1971	13.8	14.3	9.0
1972	14.3	14.3	9.0
1973	24.2	22.1	16.2
1974	21.8	22.0	15.9
1975	26.2	21.3	15.1
1976	23.2	21.3	15.0

[a]Source: [3].

except as the effect also is found in the input price of technological improvement. The declining trend of the broiler price demonstrates that the broiler price is not a critical factor of contribution to growth of the broiler industry. But even if the broiler price declines, output could increase with declining costs due to factor prices and technical changes.

Then, the remarkable growth of output increase should be explained by cost factor. As in Table 1.6, the unit cost of broiler production fell during the late 50s and 60s, and rose sharply in 1973, and then slightly declined since 1973. Generally, the unit cost was under a downward trend over the period 1955-1976. Feed cost, the largest and most important cost item, trended downward for the same period. This indicates that a decrease in input cost, relative to commodity price, is likely to be one possible factor of the rapid increase in broiler production, based on normal negative relationships between output and input price.

In addition to declining input cost, technological change should be considered since production cost is affected by technology through the production function. In the early 1950s, it took about 12 to 14 weeks for the bird to gain 3.5 pounds. Today, it takes about 7 to 8 weeks. The feed required to produce a pound of live bird has been reduced from 3 pounds in the 1950s to 2.05 pounds today. The shorter period of production and an increase in feed efficiency have come from continuous research in poultry nutrition and feeding, improvement in mechanical equipment, environmental control, and so on. These kinds of technological advances have contributed to the rapid growth of the broiler industry.

Another factor which can be considered is the structure of the broiler industry, characterized by (vertical) integration which plays the role of sharing risks associated with price and production variabilities. Another important structural change in the broiler industry is a growth of farm size, from small, independent farms throughout the country to larger specialized farms located only in certain areas. The number of farms selling broilers decreased from about 50,000 in 1954 to about 31,000 in 1974 [43, p. 3]. Vertical integration and the increasing size of the production unit are also important factors in the growth of the broiler industry.

Therefore, it can be assumed that the combination of (1) a decrease in input costs, (2) rapid technological change, and (3) change in the industry structure has contributed especially to the rapid growth of broiler production.

B. Objective of Study

This study is primarily concerned with the estimation of the broiler supply functions of the United States, based on the major behavioral and economic relationships. Questions to be answered in this study include the following:

1. What is the magnitude of supply elasticity of broiler products in the United States?
2. Is the supply elasticity decreasing with respect to an advanced technology?
3. Are broiler producers less responsive to price declines than to price increases?

The basic approach used in this study is the econometric estimation of linear supply equations, employing nationally aggregated time-series data. The period used in this study is from 1960 through 1980, recorded on a quarterly basis.

C. Source of Data

Most of the data used in this study are taken from Poultry & Egg Situation and Agricultural Prices, published regularly by U.S. Department of Agriculture, and also from the Statistical Bulletin No. 525 and its supplement for 1972-1975 to Statistical Bulletin No. 525. Throughout this study, the data cited are from these sources unless specially noted otherwise. All of the variables, except the broiler-feed conversion ratio, are available on a quarterly basis. The prices used in this study are expressed in real terms, by dividing their nominal values by the implicit GNP deflator. All data used in this study can be found in the Appendix.

D. Outline of Study

In Chapter 2, the past studies of the supply function are reviewed. The development of conceptual discussions underlying the supply function is presented, with problems in estimation of empirical supply studies.

In Chapter 3, the theoretical derivation of the supply function is presented, showing the properties of the supply function. The relationship between supply function and technology is presented, noting the difficulty of the measurement of technology. The concept of irreversibility will be noted.

In Chapter 4, the methodology used in empirical supply studies is reviewed to construct a better model of the broiler supply function. Functional forms of the supply model and specification of the irreversible supply function are presented.

In Chapter 5, specification of broiler supply models are presented, based on economic theory, production pattern and information obtained from the previous work. The quantitative index of technological change is presented.

In Chapter 6 and 7, empirical analyses of broiler supply function are presented. The results of this estimation and the interpretations thereof are shown in these last two chapters.

II. REVIEW OF LITERATURE

This part of the study summarizes the previous works which have been done on supply analysis of agricultural products. Relevant empirical works of demand and supply studies of agricultural products date back to the turn of the century. Forecasting the yield and the price of cotton by H. L. Moore [33] in 1917 may be considered as the pioneer work in this area. After Moore's work, many studies have analyzed the market demand for agricultural products. However, the number of empirical works on supply analysis has been relatively small, compared to that of demand studies. Cassel [7] explained the reason as follows:

> It is plain that the analysis of supply is more complicated and difficult than the analysis of demand. It is also plain that difficulties encountered are not peculiar to empirical approach. They are theoretical rather than statistical. The idea of a supply curve is not as neat as or as simple a concept as the idea of a demand curve [7, p. 387].

However, empirical studies of supply response of farm products are matters of great importance, regardless of the difficulties underlying the supply curve, because of the adjustment problem of farm output to market demand. Empirical attempts of supply analysis were based on two methods: (1) studies about the supply response based on empirical estimation of the production function and (2) studies of direct relationships between price and quantity supplied based on observed time series data. The first method is of little practical value, because it provides little information about the producers' response to supply. Moreover, there were difficulties in estimating production functions of farm products due to a lack of data on the amount of various production factors used in the production process. Because of these difficulties, many studies focused on the second method. The second method is more important for practical purposes. In building an empirical model by use of the second method, two different variables representing the dependent variable were used in the supply model: (1) planted acreage (i.e., supply response of planted acreage with respect to the price variable) and (2) output (i.e., supply response of output with respect to the price variable). For the use of planted acreage as a dependent variable, Cassel said, "... acreage should be used instead of output as a measure of production response. It is undoubtedly a better index of the producers' response to the price situation but it is by no means a perfect one" [7, p. 386].

Together with an empirical development of supply studies, several important conceptual discussions were made. Cassel [7] emphasized that there is no curve which can be regarded as the single supply curve for any particular commodity, with his explanations about three different types of supply curves (i.e., the market curve, the short-run normal curve and the long-run normal curve). He also said, "What we have, as a matter of fact, is a whole series of supply curves for each commodity representing all possible conditions between the most perfect long-run normal adjustments and most rigid momentary fixity of supply" [7, p. 382]. In other words, there will be a system of supply curves based on different adjustment periods between the vertical line supply curve of the very short period and the supply curve approaching a horizontal line for the very long period. Therefore, supply studies should be made very carefully with respect to the time element in responses (i.e., dependence of responses on the adjustment period allowed).

Heady [22] pointed out an identification problem in estimating supply functions. His explanation was,

> Supply and demand functions jointly affect price and quantity produced; where both are subject to change, an estimation of one function from the other may be quite meaningless. (A supply function can be estimated by least square technique only if the supply function remains constant and demand function goes through a series of changes and price and quantities are the only variables [22, p. 233].

If the supply function shifts together with the demand function, the curve which plots the quantities against prices in empirical observations shows a locus of equilibrium points of the demand and supply functions. If the supply curve shifts from S_1 to S_2, and to S_3 as in Figure 2.1 with its corresponding shifts in the demand curve from D_1 to D_2, and to D_3, then the equilibrium points move from a to b, and then to c. The locus of the equilibrium points such as the M curve in the figure is called a "mongrel" line by Heady. The mongrel line is different from either the demand curve or the supply curve, since it simply shows a relationship of price and quantity when the demand and supply curves shift simultaneously. Therefore, the mongrel line does not have any functional relationship between price and quantity as the demand and supply curves do.

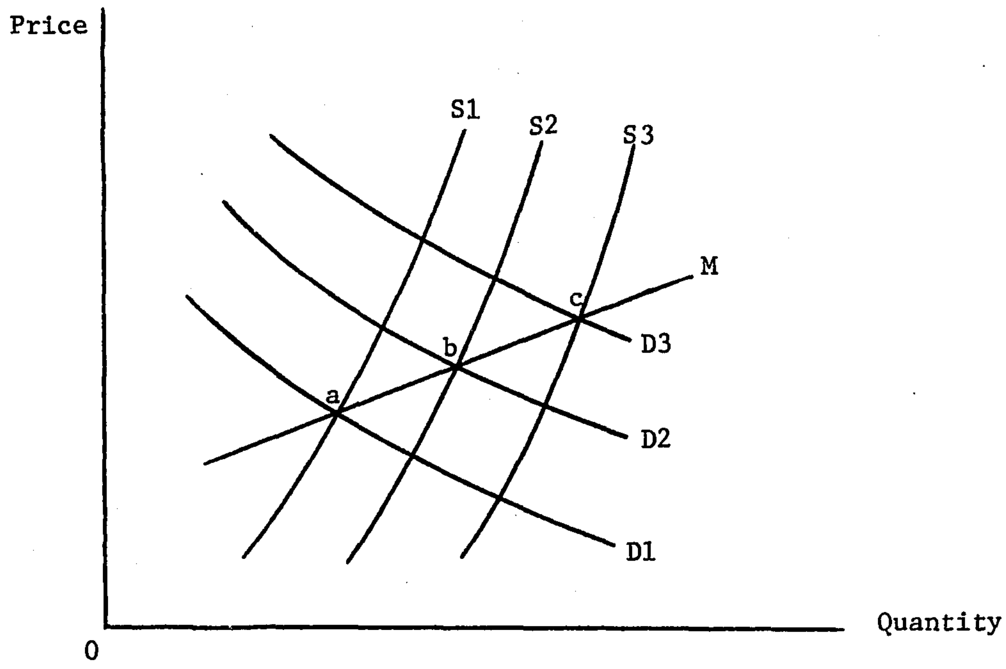

Figure 2.1. Mongrel curve

Cochrane [11] made a conceptual distinction between two terms: (1) supply relation and (2) response relation. Cochrane said,

> By the term supply relation, or supply function, economists trained in the equilibrium tradition have in mind how the quantity of a product offered for sale varies, as its price varies relative to other prices, for some given time period and for a given state of arts, or technology. By the term response relation, or response curve economists have in mind, or should have in mind it is argued here, how the the quantity of a commodity offered for sale varies with changes in the price of the commodity [11, p. 1162].

In other words, the response relation describes the movement of the quantity of a commodity supplied when we do not hold all other things constant, while the supply relation is related to quantity supplied to price when all other things (e.g., technology) are held constant. Therefore, the response relation is a more general concept than the supply relation is, and is a mongrel line in Heady's sense. The supply response relation is more useful for a predictive purpose (i.e., predicting the change in quantity supplied with respect to particular change in price).

Schultz [46] emphasized agricultural production and supply by saying "most of relevant knowledge of consumption and demand is at hand and the important economic problems of agriculture call primarily for adjustment in production" [46, p. 748]. As noted by Schultz, quite an amount of theoretical and empirical knowledge has piled up in demand studies, while the study of agricultural supply is a neglected area.

The active studies of demand for agricultural products can be explained by borrowing a theoretical background. Price and income elasticities of demand for food are relatively low and it may be assumed that they will continue to be relatively low. This can be clearly illustrated by a developed country such as the United States in which (1) a small portion of income is spent on food and (2) changes in price do not have much effect on quantity demanded since food is essential. This is why consumption patterns have been relatively stable over time. The stability of demand function depends on what happens to taste, and in reality, taste remains fairly stable. Here, Schultz's words are cited again: "For a function to be useful it must either be stable over time, or we must be able to predict how it will change" [46, p. 750]. Therefore, under Schultz's concept, a stable demand function has contributed greatly to active empirical studies.

On the other hand, the stability of supply function depends on what happens to technology and factor prices. In the real world, technology does not remain stable. Technology employed in agricultural production has been changing constantly and is considered to be very important for agricultural development. According to Schultz, "output rose from 100 (for 1869-1873) to 1950 (for 1949-1953), while the additional inputs rose from 100 to about 468 during the same period" [46, p. 755]. Therefore, additional inputs, with the assumption of constant returns, account for about one-fifth of additional output. This demonstrates that additional output in agricultural production does not come from additional inputs of the conventional types. Schultz explained the excess of incremental output over incremental inputs by the new technique adopted in production and by improvements in labor force. Therefore, all studies are comparatively useless, in Schultz's sense, unless we can predict the changes in technology.

Together with conceptual contributions to agricultural supply functions, Nerlove [34] emphasized the need for reconsideration of statistical results of empirical supply studies employing time series data, by posing a question, "Why have such low elasticities of acreage with respect to price been obtained?" He formulated and applied a price expectation model, by using distributed lags, for the estimation of a time series supply model of farm products. He assumed that farmers react, not to last year's price, but rather to the price they expect, and this expected price depends only to a limited extent on what last year's price was. His distributed lag models resulted in higher elasticities, defending his position, and making it possible to obtain two separate elasticities for short run and long run. He called his procedure "general" method because it allowed the data to determine the coefficient of expectation, and said "Qualitatively, at least, the estimates obtained by the general method are more reasonable than those obtained when the coefficient of expectation is arbitrarily assumed to be one" [34, p. 506]. The Nerlove studies were considered to be one of the most important contributions to time-series supply analysis, even though much criticism was made of the procedure.

Another conceptual discussion underlying the agricultural supply function has been the irreversible nature of the supply response. Cassel

[7] pointed out the one-way nature of the supply curve, and said, "the process of contraction is not an exact reversal of the process of expansion and consequently the elasticities for the upward movement and the downward movement may be entirely different" [7, p. 387]. Cochrane is considered to be the first agricultural economist using the word "irreversible" in his distinction between supply relation and response relation. According to Cochrane, the output supply relation is reversible, while the output response relation is not reversible. He explained that technological progress is considered in the response relation, while it is held constant in the supply relation. Thus, the output response curve is more elastic in the price-increasing phase than in the price-decreasing phase.

The fixed asset theory by G. L. Johnson [26 and 27] provides the theoretical background for the irreversible supply response. He said, "aggregate supply curve for agriculture is more elastic upward than downward" [26, p. 86], and continued, "the fixed asset theory used herein would indicate that a high proportion of the influence of these shifts on the aggregate supply function is only partially reversible" [26, p. 92]. He proposed, "Needed empirical research on aggregate supply responses must consider the partial irreversibility of the aggregate supply function" [26, p. 93].

In empirical studies of irreversible supply response, Halvorson [16] estimated four separate supply functions for rising and falling prices in the summer and winter seasons, respectively, in his milk supply studies. His results suggested the possibility that the short-run response to a price increase is more elastic than the response to a price decrease. The first attempt to incorporate variables for an increasing-price and a decreasing-price into a single equation supply model was made by Tweeten and Quance [53]. Their estimation results with similar values of coefficient estimates for an increasing price and a decreasing price did not support the irreversible nature of farm output supply. Wolffram [64] criticized the method employed by Tweeten and Quance, and showed that Tweenten and Quance's method for the formulation of the irreversible supply function is mathematically incorrect. Wolffram proposed his own method which is now generally accepted. After Wolffram, many economists have proposed different methods to formulate irreversibility, and have provided their own results for supporting the irreversible phenomena of supply response. More details will be presented in Chapters 3 and 4.

So far, a rough review of the development of supply studies has been made. Considering the many past studies, Nerlove's work can be considered as a milestone in empirical approach, and has been widely adopted by agricultural economists for their own needs during the last two decades. Nerlove and Bachman [37] summarized past supply studies, and later Tomek and Robinson [51] also provided a general review of past supply studies. Askari and Cummings [1] provided an overall summary of the Nerlovian-type supply studies.

A relatively few studies have been conducted on the analysis of broiler production. Fisher [14] estimated farm supply of chickens by employing variables of the farm price of chickens and eggs, corn price, number of chickens on the farm, and time trend in his studies of the poultry industry. He did not employ farm wage-rate, and said, "labor plays a relatively small part in the production function and generally even in commercial farms takes the form of unpaid labor" [41, p. 41]. His estimation shows that the price variables are not relatively significant, however, he got significant estimates of the farm chicken price by adding a feed price variable to the basic variables above. His explanation was the possible interrelationships in the supply equation of quantity and price of the related products.

Hayami [18] conducted broiler supply analysis in his studies of the poultry supply functions by using a Nerlovian-type adjustment hypothesis. His model was expressed in the linear-in-logarithms function, employing variables of the broiler feed price ratio, egg profitability index, and technology index of the broiler industry. His estimations resulted in statistically insignificant estimates of price variables. He explained his results by the use of rapid progress in broiler production technology and simultaneous bias in the least-square estimates. He explained the first reason in the following way:

> Total output of broilers has increased almost consistently since 1934, because the increase in the efficiency of production has more than offset the effect of price fall in the years of unfavorable market. The price fluctuations must have had a small effect on the total output of broilers, relative to the increase in efficiency due

> to technological progress. The effect of technological progress must overshadow the effect of the change in broiler price in the statistical estimation [18, p. 131].

His simultaneous-equation approach of demand and supply of broilers was unsatisfactory and resulted in one positive and one negative sign for the two broiler-feed price ratios employed in the supply model. His emphasis was the effect of technological progress on the producers' response to price. His explanation with his statistical results was:

> ... technological progress seems to have shifted broiler supply upward rather than changed the elasticity. Technological progress might have increased or decreased the price elasticity of broiler supply. But the effect of the change on elasticity is relatively small so that it is overshadowed by the shift of the supply curve [18, p. 139].

Heien [23] estimated a broiler supply function in his poultry sector analysis. His supply function was the production of broilers plus ending stocks of broilers lagged one year. Production and ending stocks euqations were estimated. In his production equation, two price variables, WPBC/FCV and WPBC/WRPP, were employed with a time trend and capacity of the broiler industry, where WPBC is the wholesale price of broiler chicken, FCV is the feed cost variable, and WRPP is the wage rate in poultry processing industry. However, he did not talk about the supply equation itself, but focused mainly on the cross price effect among various meats.

Chavas [9] explained the broiler industry by using eight equations and one identity: placement, testing, hatching, production, farm price, retail price, wholesale price, stock equations, and utilization identity. As proved by the equations, he tried to explain production by using a multi-step analysis from the placement stage to the production stage. His broiler production equation was expressed, in a linear model, in terms of broiler hatching, real feed cost, real wholesale price of broiler, and seasonal dummy variables. The coefficient estimate of price variable was statistically significant, and has the sign consistent with economic theory. The elasticities of production were 98 percent with respect to placement, 29 percent with respect to hatching, and 9 percent with respect to the wholesale price of broilers. With these results, he said, "the elasticities are higher at early stages, decrease during the production process, and approach zero in the last stage of productions" [9, p. 128].

So far, a simple and neat review has been presented of the development of conceptual and empirical works of agricultural supply as a whole and of the broiler supply model. In the next two chapters, a theoretical and empirical background will be presented to construct a better broiler supply model.

III. PROPERTIES OF SUPPLY FUNCTION

This chapter develops an economic theory that would be useful for building an aggregate supply model for the broiler industry in the United States. Therefore, the purpose of this chapter is to consider methods of constructing a model for the broiler supply function. A supply function is a relationship between the price offered and the quantity supplied of a commodity with possible influential factors. The critical step in building a supply function lies in finding what kind of specific variables in addition to product price should be included in the function. For this purpose, a theoretical derivation of supply function will be presented shortly.

A. Derivation of Supply Function

The basic unit of production is a firm. The typical objective of a firm, from the formal point of view, is assumed to be profit maximization, subject to a given set of technology and institutional constraints. Profit equals revenue minus cost. Revenue is the level of output multiplied by the product price, and cost is the sum of the level of input(s) times the price of each input. In the neo-classical formulation, technology is generally represented by a production function which defines a relationship between a set of inputs used in production and the maximum level of output attainable. Mathematically, the production function of a firm which utilizes n-input to produce a single output is expressed:

$$Q = f(X_1, X_i, \ldots, X_n) \tag{3.1}$$

where Q is quantity of output, and

X_i is quantity of i^{th} input; $i = 1, 2, \ldots, n$.

The production function is assumed to be a single-valued continuous function, twice differentiable and concave for non-negative values of the inputs and output level. Institutional constraints are generally represented by the market structure of the industry in which the firm is operating.

Since the firm is assumed to maximize profit, the firm's objective is expressed by:

$$\text{Maximize } \pi = PQ - \sum_{i=1}^{n} R_i X_i \tag{3.2}$$

where P is product price,

Q is output produced,

R_i is i^{th} input price, and

X_i is i^{th} input used; $i = 1, 2, \ldots, n$.

Then, the objective of the firm is to choose the output and input levels so as to maximize profit. Here, the firm is assumed to be a perfectly competitive firm whose prices of output and all inputs are given parameters.

The first-order conditions for profit maximization are:

$$P \frac{\partial Q}{\partial X_i} = R_i; \; i = 1, 2, \ldots, n. \tag{3.3}$$

Equation 3.3 is homogeneous of degree zero in input and output prices. In other words, a percentage change in all input and output prices would not alter the optimal conditions of production. The equation implies that the value of marginal product should be equal to the input price for profit maximization. Solving the n-equation in Equation 3.3 provides the optimal level of each input for profit maximization. That is,

$$X_i^* = X_i[P, R_1, R_2, \ldots, R_n]; \; i = 1, 2, \ldots, n. \tag{3.4}$$

Equation 3.4 is called the system of factor demand functions or derived demand functions. The factor demand functions are also homogeneous of degree zero in input and output prices. Substituting the optimal level of each input into the production function gives the optimal level of output for profit maximization. That is,

$$\begin{aligned} Q^* &= f[X_1^*, X_2^*, \ldots, X_n^*] \\ &= f[P, R_1, R_2, \ldots, R_n] \end{aligned} \tag{3.5}$$

Equation 3.5 is called the output supply function. If all input prices are held constant, then the equation becomes

$$Q^* = f[P, \overline{R}_., \overline{R}_2, \ldots, \overline{R}_n] \tag{3.6}$$

Equation 3.6 is called the output supply curve. The output supply function of an individual firm under perfect competition is homogeneous of degree zero in output and all input prices.

Mathematically,

$$Q^*(kP, kR_1, kR_2, \ldots, kR_n) = Q^*(P, R_1, R_2, \ldots, R_n) \qquad (3.7)$$

where k > o

Therefore, an individual firm's supply function is derived under the assumption that all the prices are given parameters to the firm. This seems a reasonable assumption under perfect competition because an individual firm is so small relative to the firms in the industry that its changes in purchases of inputs and in sales of output do not affect the market prices of the inputs and output. The firm's supply function, derived under conditions of profit maximization, is determined by the prices of output and input under perfect knowledge of prices and production function.

However, there is a problem in aggregating the individual supply function for the industry supply function. When all firms in the industry simultaneously change their output level, there may be tangible effects on the input and output markets; input prices change and each firm's cost curve changes -- hence, each firm's supply surve shifts. For example, if all firms in the industry significantly increase their production levels of output, then there must be an upward movement of price of inputs. The movement of input prices affects the cost structure of each firm, and hence the supply function. If input prices change with respect to a change in use of the input, an industry supply curve cannot be obtained by horizontal summation of each firm's supply curve. This is because an individual firm's marginal cost curve (therefore, supply curve) shifts simultaneously with a change in input price. If input prices increase with respect to an increase in industry output through increased use of inputs (i.e., an increasing cost industry), then the industry supply curve is somewhat more steeply sloped or less elastic. Therefore, the concept of a competitive industry supply curve is less precise. Thus, more information is necessary to find the exact industry supply curve.

However, the industry supply curve is perfectly determinate. It is the sum of the quantities supplied by all individual firms in the industry, which is determined from the marginal cost curves corresponding to the current set of input prices. As a rough approximation, the industry supply curve can be regarded as a horizontal summation of the individual short-run supply curves of all individual firms in the industry. Its shape is largely determined by the number of firms in the industry, the size of individual plants, other factors determining the cost curves of each firm, and the effect of changes in the industry output on input prices.

B. Effects of Technology on Supply Function

Mansfield [32, p. 10] defines technology in the following way: "Technology is society's pool of knowledge regarding the industry arts." He continued, "It consists of knowledge used by industry regarding the principles of physical and social phenomena, knowledge regarding the application of these principles to production, and knowledge regarding the operation of production." Thus, technological change is an advance of knowledge which depends on research and development carried out in the society as a whole.

In an economic sense, technology at a given point of time is represented by the production function, showing a maximum level of output which is attainable from a given set of inputs. Technological change is demonstrated through a change in the production function. Consider the following production function:

$$Q = F[X_1, X_2, \ldots, X_n, t] \tag{3.8}$$

where Q is output,

X_i is i^{th} input; $i = 1, 2, \ldots n$, and

t is time trend.

The variable t for time is included in functional form F to allow for technological change. Assume the production function is subject to constant returns to scale, and technological change is neutral. Technological change is neutral if marginal rate of technical substitution remains unchanged after technological change takes place. In this case, the production function can be expressed as:

$$Q = A(t) \cdot f(X_1, X_2, \ldots, X_n) \tag{3.9}$$

where A(t) measures the shift of production function over time. Take total differentiation of Equation 3.9 with respect to time and divide by Q. Then,

$$\frac{1}{Q}\frac{\partial Q}{\partial t} = \frac{1}{A}\frac{\partial A}{\partial t} + \sum_{i=1}^{n}\left(\frac{X_i}{Q}\frac{\partial Q}{\partial X_i}\right)\left(\frac{1}{X_i}\frac{\partial X_i}{\partial t}\right) \; ; \; i = 1, 2, \ldots, n \qquad (3.10)$$

or

$$\frac{\mathring{Q}}{Q} = \frac{\mathring{A}}{A} + \sum_{i=1}^{n} w_i\left(\frac{\mathring{X}_i}{X_i}\right); \quad i = 1, 2, \ldots, n. \qquad (3.11)$$

where $\mathring{M} = \frac{\partial M}{\partial t}$: $M = Q$, A, and X_i,

$w_i = \frac{X_i}{Q}\frac{\partial Q}{\partial X_i}$ = relative share of i^{th} input over total value of product

Then, the first term $(= \frac{\mathring{A}}{A})$ represents the relative shift in the production function caused by a technological change.

Since a supply function is derived by using a production function, and since the production function is affected by technological change over time, then the supply function must be affected by technological change. If $A(t)$ increases by 20 percent from time t_o to time t_1, then marginal product (MP) of each input will also increase by 20 percent since

$$\text{MP of the } i^{th} \text{ input} = \frac{\partial Q}{\partial X_i} = A(t)\,\frac{\partial f}{\partial X_i}$$

An increase in marginal product of each input brings a downward shift of the marginal cost curve and consequently, the supply curve, since marginal cost (MC) is equal to input price divided by its marginal product for a perfectly competitive firm. That is,

$$MC = P = \frac{R_i}{MP_i} \qquad (3.12)$$

where P is output price.

Assuming constant input price, the 20 percent increase in A(t) would lower MC as follows:

$$\frac{R_1}{1.2MP_1} = \frac{R_2}{1.2MP_2} = \ldots\ldots\ldots = \frac{R_n}{1.2MP_n} = 0.83\ MC_o = MC_1 \qquad (3.13)$$

where MC_o is original marginal cost, and

MC_1 is new marginal cost with a 20 percent increase in A(t).

As noted by Equation 3.13, technological progress moves the marginal cost curve downward. Consequently, the supply curve shifts as a result of a technological change. This demonstrates the importance of technological change in an analysis of the supply function.

The problem is to find a proper variable representing technological change to be included in an empirical supply function. One possible way is to estimate a series of production functions for each period of time, and to measure $(\frac{\mathring{A}}{A})$ as noted earlier. This method will depend largely on the assumption about the shape of the production function used (that is, Cobb-Douglas production function, or Constant elasticity of substitution production function, or other type production function). Various types of production functions can be employed for an estimation purpose and each production function possibly gives a different value of $(\frac{\mathring{A}}{A})$. That is, there is no one-and-only measure of $(\frac{\mathring{A}}{A})$ in using this method. Moreover, there are difficulties in this method because it might be infeasible for a practical purpose to find enough data to estimate a sufficient number of production functions in order to evaluate the technological change over time.

Another way is to use an input-output ratio as an index of technological change. An input-output ratio at a certain point of time represents an average productivity for a particular level of input under a given market condition.

Consider a simple production function with one output and one input:

$$Q = f(X) \tag{3.14}$$

In Figure 3.1, lines CC' and DD' are tangent to the production function at points A and B, respectively. Since the optimal condition for production in a competitive firm is equating marginal value product and input price, as in Equation 3.3, production occurs at point A if the input-output price ratio is given by line CC'. In this case, the input-output ratio is OA/OA'. The input-output ratio is given by OB/OB' when the input-output price ratio is represented by line DD'. This suggests that an input-output ratio can be affected by a change in the price ratio of input and output. It can be said that there are two factors affecting an input-output ratio: (1) change in the production function and (2) change in market conditions.

Our purpose is to find a pattern of changes in the production function over time to be used as a technological index. However, there are difficulties in determining whether a change in an input-output ratio comes from either a change in the production function or a change in the input-output price ratio. For the use of the input-output ratio as a

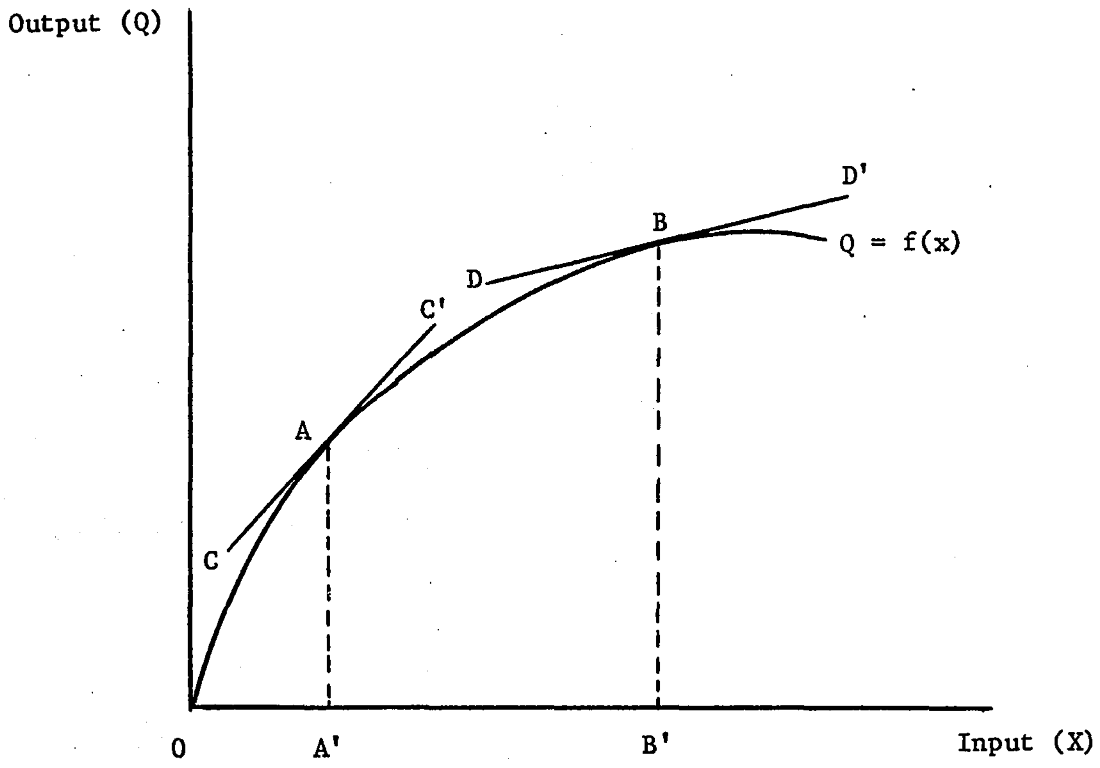

Figure 3.1. Input-output ratios for a given production function

variable for technological change, Hayami [18, p. 28] mentioned three following conditions, at least one of which would be satisfied: (1) the effect of a change in the input-output price ratio is so small relative to that of a change in the production function that the effect of a change in the input-output price ratio could be neglected, (2) the effect of a change in the input-output price ratio follows a certain pattern over the sample period, so that the effect can be eliminated by a certain type of method, or (3) there is a certain trend of a change in the production function over the sample period, so that the effect of a change in the production function can be estimated.

Numerous attempts have been made to devise a better measure of the rate of technological change. However, there are still problems of measuring technological change; we still do not have a general measurement of the rate of technological change. Thus, it is necessary to find a factor as a variable for technological change, which accounts for contribution to the growth of the industry, as a second best way.

C. Irreversibility of Supply Function

Theoretical arguments in favor of an asymmetric supply response to increasing and decreasing prices were proposed by J. M. Cassel, and conceptualized by W. W. Cochrane, and advanced by G. L. Johnson.

Cassel [7] emphasized two natures of the economic relationships of a supply curve: one is the time character of a supply curve and another is the one-way nature of a supply curve. He proposed that the process of decreasing output due to a price fall is not an exact reversal of the process of increasing output with rising prices and the supply curve is commonly a one-way nature. The explanation can be made by borrowing his arguments:

> Just because a given increase in price called forth a given increase in supply it does not follow that a decrease in price of the same amount would restore the output to its former level. When production is once established on a particular level there are forces of economic inertia which tend to maintain it at least for a time. Capital once fixed in a specialized form cannot quickly be withdrawn, and entrepreneurs committed to a particular line of production will commonly continue to produce even when the price they receive does little more than cover the direct cost of operation [7, p. 384].

Cochrane [11] provided a detailed explanation of the irreversible phenomena of output response relation. If there is an increase in price, possibly due to an increase in market demand, it is reasonable to expect that there is an increase in output supplied, based on normal assumption of positive relationships between output supplied and price. In this case, the increase in output supplied may be due to an increased use of production factors, technological progress, and/or some combination of the two. If price goes down possibly due to a decrease in market demand, then there is a decrease in output, based on the same assumption, but the decreasing path of output is not the same path of increasing output. In other words, there is one output path for increasing price and another path for decreasing price. This can be explained by the fact that producers will try to hold an advanced production technology which is taken when price is rising, because a technological progress usually reduces unit cost by shifting cost curves downward. When output price is falling, it is expected that some of inputs used is transferred into other uses. However, the advanced production technology, obtained during the price-increasing phase is generally maintained rather than given up, because unit cost is lower with advanced technology than without it.

Suppose that at an initial stage, quantity OA in Figure 3.2 is produced at price OP_1. If there is an increase in price to OP_2, then output will be increased from OA to OB. However, if price falls back to OP_1, output will be contracted to OC rather than OA. Thus, the output response is more elastic with respect to the increasing price rather than with respect to the decreasing price, as explained by Cassel and Cochrane. This kind of property of the output response to price is called "irreversible or non-reversible."

Johnson [26 and 27] in his fixed asset theory provided more theoretical background on the irreversible nature of output supply. His fixed asset theory is based on neo-classical marginal analysis. The law of diminishing returns determines the nature of marginal cost curve of individual producers, and hence, of the industry supply curve. The rate of a decrease in marginal product of variable inputs depends on (1) the proportion of fixed inputs, (2) the levels at which they are fixed, and (3) the degree of substitutability or complementarity between fixed and variable inputs. He said, "it is extremely important that the framework employed in analyzing supply problems be capable of determining:

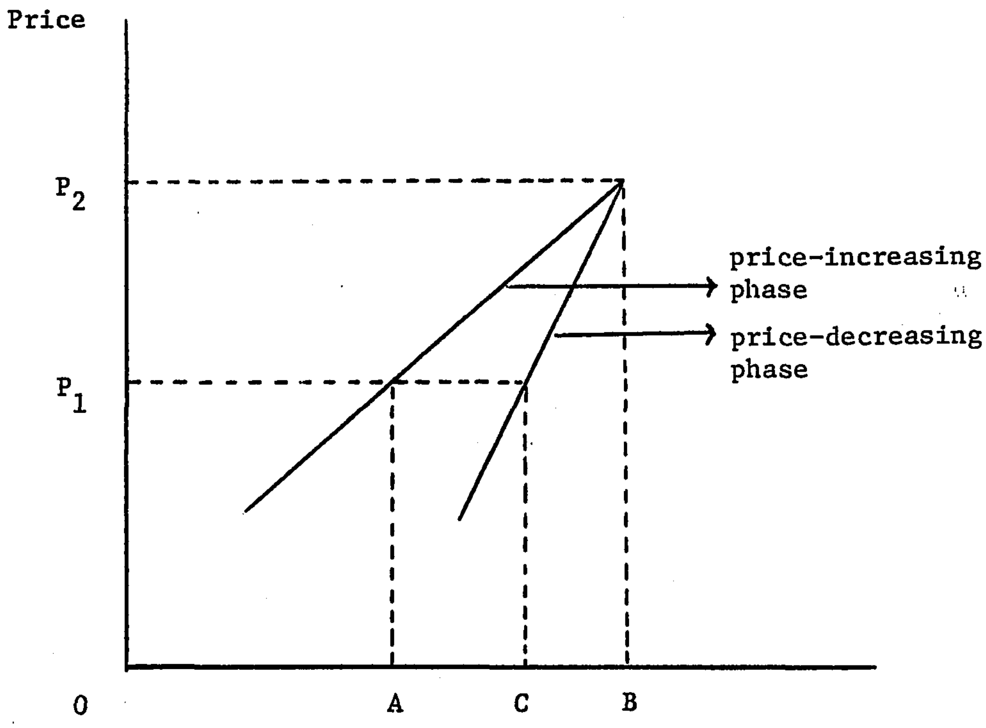

Figure 3.2. Output response curve for some commodity

(1) which assets are fixed and (2) the levels at which they are fixed" [26, p. 81].

In agriculture, farm producers have two prices of inputs: (1) acquisition cost, or price at which they acquire inputs, and (2) salvage value, or price at which they sell the inputs. Of course, there are differences between acquisition costs and salvage values. Consider a simple production function with one output and two inputs.

$$Q = f(X_1, X_2) \tag{3.15}$$

where Q is output produced,

X_1 is variable input, and

X_2 is fixed input (or service of durable goods in Johnson's sense).

Johnson's definition of a fixed input is based on satisfaction of the following inequality:

$$\text{SV of } X_i < \frac{\partial Q}{\partial X_i} \cdot P = \text{MVP of } X_i < \text{AC of } X_i \tag{3.16}$$

where SV is salvage value,

AC is acquisition cost,

P is output price, and

X_i is i^{th} input; i = 1, 2.

If the inequality holds, then X_2 is fixed at a given level for the production period to be considered [27, p. 445]. Assuming that the inequality holds for input X_2, the fixity of X_2 provides the law of diminishing returns of output with respect to the input use of X_1.

Consider Figure 3.3 for the relation between output price and input use of X_1, given that X_2 is fixed at some level. At the original stage, use of variable input X_1 is fixed at OA, given the price of output, (OP_o in Figure 3.4). If output price increases (to OP_3 in Figure 3.4), then Marginal Value Product (MVP) curve shifts upward to MVP' in Figure 3.3. As a result, more X_1, OB, will be employed in production, because MVP of X_1 is greater than the acquisition cost of X_1. On the other hand, a decrease in price of output (OP_2 in Figure 3.4) shifts the MVP curve downward to MVP", and input use of X_1 will be contracted to OC in Figure 3.3. However, there would be no change in use of input X_1 as long as the inequality 3.16 holds under changing price of output.

Under this situation, the marginal cost curve is discontinuous at $Q = f(OA \text{ of } X_1, \text{ given } X_2)$. Beyond this point, marginal cost of output would be acquisition cost of X_1 divided by its marginal product. For output less than $Q = f(OA \text{ of } X_1, \text{ given } X_2)$, marginal cost would be lower than for $Q = f(OA \text{ of } X_1, \text{ given } X_2)$. Therefore, with OA of input X_1, given X_2, the marginal cost curve associated with changing price of output would be abcde in Figure 3.4, while MC curve with OB of input X_1 would be abc'de. Based on these characteristics of discontinuous marginal cost curve, Johnson said, "aggregation of movements within such marginal cost structures should produce commodity supply functions which display discontinuities and different elasticities for expansion than for contractions" [27, p. 449].

Johnson and Pasour [28] demonstrated the inappropriateness of using

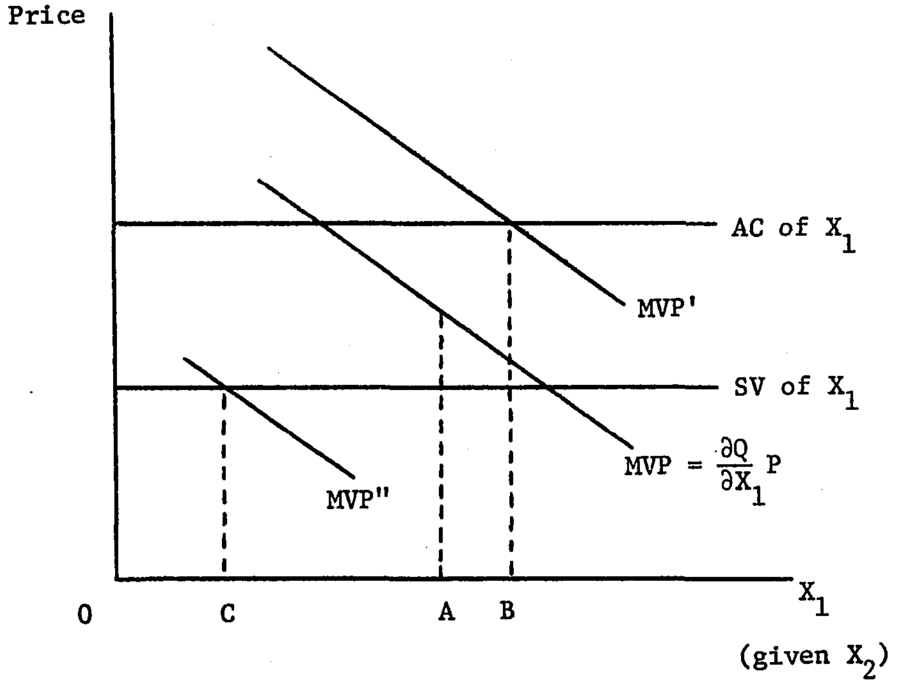

Figure 3.3. Input use with a change in output price

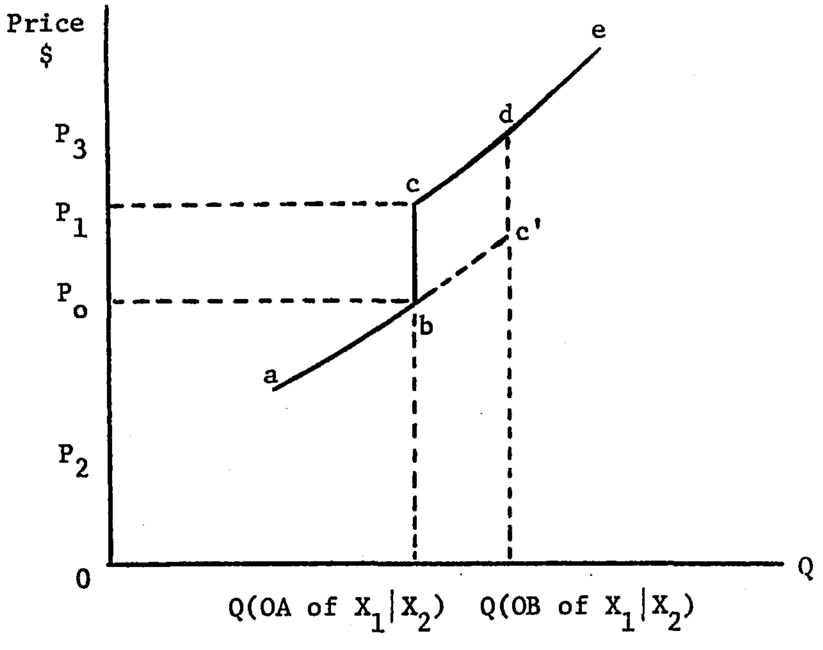

Figure 3.4. Marginal cost curve with changes in input use and output price

the fixed asset theory to judge entrepreneurial efficiency by using a concept of opportunity cost. Since the purpose of this part is not a discussion of the fixed asset theory itself, but a discussion of the irreversibility suggested by the theory, no more discussion is presented on the fixed asset theory. However, they generally endorsed the irreversible supply function by saying, "..., the theory can contribute toward an understanding of why the supply function, whether firm or industry, is not reversible and is more elastic the longer the length of run" [28, p. 6].

Statistically estimated supply curves generally relate to single linear equation models, ignoring the property of irreversibility of supply response curve. A single equation model on a linear-in-logarithms functional form implies that price elasticity of supply is constant for both price-increasing and decreasing phases, but there is no a priori reason to believe that the elasticity is the same for both phases. If we are concerned with output expansion (contraction), then our interest will be the elasticity of the upper curve (lower curve) in Figure 3.2. Therefore, there is a need to specify and estimate an irreversible supply model. Details in estimation techniques will be presented in Chapter 4.

IV. METHODOLOGY OF SUPPLY MODEL

A wide range of empirical techniques have been employed to analyze the supply of agricultural products. The empirical studies related to agricultural supply responses of farm products can be divided into three main categories. First is the statistical analysis of the supply response of a particular commodity based on time-series data. Second is the studies based on the mathematical programming model or budgeting technique using typical farms or regions, involving the derivation of supply functions. The third is the studies estimating the supply response of total farm output to changes in product and factor prices, including the development of a theoretical concept.

Each technique has an advantage and a limitation for particular purposes. Even though the empirical technique employed is satisfied with the conditions underlying the economic, mathematical and statistical theory, the availability of data and its measurement is indeed another thing.

Among the various techniques, statistical time-series regression analysis has been most frequently employed for agricultural supply studies of farm products. For the time-series supply studies, aggregate data such as nationally averaged corn price at farm level have been employed to estimate the supply function. Based on statistical reason(s), only a few relevant variables which seem to be important to explain the supply structure have been used. This analysis deals directly with the relationship between the variables, such as total quantity produced and national average price, which are of interest in the decision-making of policy. Since statistical analysis is employed in this study, focus will be placed on specification and functional form for the estimation of single equation supply model.

A. Nerlovian Supply Model

The most significant contribution to time-series supply analysis has been Nerlove's work. His contribution is in the formulation and application of a price expectation model to the estimation of supply function of selected agricultural commodities. His distributed lag models, based on the adoptive expectations model and partial adjustment model, make it possible to obtain two separate estimates of short-run and long-run elasticities.

The Nerlovian supply model, based on Koyck, has been adopted, modified, and revised in numerous studies of estimating supply functions. The general form of the Nerlovian model is expressed as follows:

$$Q_t^* = \alpha_o + \alpha_1 P_t^* + \alpha_2 Z_t + U_t \qquad (4.1)$$

where Q_t^* is the desired output at time t,

P_t^* is expected price at time t,

Z_t is the non-price variable at time t, and

U_t is random distribution term.

Equation 4.1 states that the desired level of output at time t is a linear function of the expected price and non-price variable at time t. The problem with the equation is that the desired output and expected price is not observable. Therefore, an additional assumption(s) is needed to identify the desired output and expected price.

The first assumption is the adoptive expectations model. This hypothesized that each year farmers revise the price they expect to prevail in the coming year in proportion to the error they made in predicting price this period. This model implies that the actual output is equal to the desired output, but the expected price is not equal to last year's price. Mathematically, the expectations function is expressed:

$$P_t^* - P_{t-1}^* = \beta(P_{t-1} - P_{t-1}^*); \quad 0 < \beta \leq 1 \qquad (4.2)$$

where β is coefficient of expectations, and

P_t is actual price at time t.

The assumption is equivalent to stating that the expected price is represented as a weighted moving average of the past prices, where the weights are functions of the coefficient of expectations. That is, from Equation 4.2,

$$\begin{aligned} P_t^* &= \beta P_{t-1} + (1 - \beta)P_{t-1}^* \\ &= \beta P_{t-1} + (1 - \beta)\beta P_{t-2} + (1 - \beta)^2 P_{t-2}^* \\ &\vdots \\ &= \beta P_{t-1} + (1 - \beta)\beta P_{t-2} + (1 - \beta)^2 \beta P_{t-3} + \cdots\cdots. \end{aligned}$$

Since the coefficient of expectations is between zero and one, the weights become smaller and smaller as we go back in time. Thus, the assumption demonstrates that the influence of more recent prices on the expected price should be greater than that of less recent prices. Moreover, even though all the past prices must be theoretically included, the declining weights provide the basis that the prices in the very distant past can be safely ignored.

The second assumption is the partial adjustment model. This model assumes that the change in actual output is proportional to the difference between the desired and actual outputs. It implies that the desired output is not equal to the actual output, but that expected price is equal to last year's price. The adjustment function is expressed as:

$$Q_t - Q_{t-1} = \gamma(Q_t^* - Q_{t-1}), \text{ where } 0 < \lambda \leq 1 \tag{4.3}$$

where γ is the coefficient of adjustment, and

Q_t is actual output at time t.

The adjustment function says that in the current period the farmer will move only part of the way from his starting position, Q_{t-1}, to the optimal position, Q_t^*. The greater the γ to unity, the greater the adjustment made in the current period. Thus, Nerlove's model basically consists of the three equations 4.1, 4.2, and 4.3. That is, the equation system used by Nerlove is:

$$\begin{aligned} Q_t^* &= \alpha_o + \alpha_1 P_t^* + \alpha_2 Z_t + U_t \\ P_t^* - P_{t-1}^* &= \beta[P_{t-1} - P_{t-1}^*] \\ Q_t - Q_{t-1} &= \gamma[Q_t^* - Q_{t-1}] \end{aligned} \tag{4.4}$$

Combining the three equations in 4.4, the final form or reduced form will be:

$$Q_t = \beta\gamma\alpha_o + \beta\gamma\alpha_1 P_{t-1} + \{[(1 - \gamma) + (1 - \beta)]Q_{t-1} - (1 - \gamma)(1 - \beta)Q_{t-2}\} + [\gamma\alpha_2 Z_t - (1 - \beta)\gamma\alpha_2 Z_{t-1}] + [\gamma U_t - (1 - \beta)\gamma U_{t-1}] \quad (4.5)$$

Equation 4.5 is the basic Nerlove model, achieved by combining two assumptions of the adoptive expectations and the partial adjustment models. The equation contains only observable variables.

If only the adoptive expectations model is assumed (i.e., $\gamma = 1$ or the desired output equals the actual output in equation system 4.4), then Equation 4.5 becomes:

$$Q_t = \beta\alpha_o + \beta\alpha_1 P_{t-1} + (1 - \beta)Q_{t-1} + [\alpha_2 Z_t - (1 - \beta)\alpha_2 Z_{t-1}] + [U_t - (1 - \beta)U_{t-1}] \quad (4.6)$$

On the other hand, if only the partial adjustment model is assumed (i.e., $\beta = 1$ or the expected price equals the last year's price in the equation system 4.4), Equation 4.5 reduces to:

$$Q_t = \gamma\alpha_o + \gamma\alpha_1 P_{t-1} + (1 - \gamma)Q_{t-1} + \gamma\alpha_2 Z_t + \gamma U_t \quad (4.7)$$

The differences between Equations 4.6 and 4.7 are the assumptions about the behavior of the disturbance terms and the containing of Z_{t-1} in Equation 4.6. If the specification of the basic model in Equation 4.1 is changed by deleting the non-price variable, then the final equation (or reduced form) of the two models will contain exactly the same variables.

The reduced form of the adoptive expectations model without non-price variable will be

$$Q_t = \beta\alpha_o + \beta\alpha_1 P_{t-1} + (1 - \beta)Q_{t-1} + [U_t - (1 - \beta)U_{t-1}] \qquad (4.8)$$

The reduced form of the partial adjustment model without non-price variable will be

$$Q_t = \gamma\alpha_o + \gamma\alpha_1 P_{t-1} + (1 - \gamma)Q_{t-1} + \gamma U_t \qquad (4.9)$$

Therefore, Equations 4.8 and 4.9 are in the form of

$$Q_t = \pi_o + \pi_1 P_{t-1} + \pi_2 Q_{t-1} + V_t \qquad (4.10)$$

Assuming that Equation 4.1 is the long-run supply function, the coefficients of the long-run supply function may be derived from estimates of the coefficients of the reduced form of each model. Therefore, long-run supply elasticity for each model may also be derived.

Equation 4.10 is the basic form that Nerlove applied to estimate the short-run and long-run elasticities of the supply of selected agricultural commodities in the United States. Most of the Nerlovian-type supply studies have been based on the use of either adoptive expectations or partial adjustment models. Even under wide acceptance of Nerlove's model, many criticisms still remain. The adoptive expectations model was criticized due to its assumption that the actual output is adjusted immediately to the expected price with exception of the disturbance term. The partial adjustment model was also criticized because of its assumption that the desired output depends only on last year's price. Even though a more general model is achieved by combining the two models of adoptive expectations and partial adjustment, it is impossible to obtain estimates of each value (i.e., coefficients of expectations and of adjustment) from the regression coefficients.

Another model using distributed lag is the rational expectations hypothesis. Rational expectations are the conditional expectations of the variable being forecast using all information available in the model structure. That is, the expected price for period t + 1 at period t is equal to the expected value of the market price for period t + 1, conditional on information available at period t. Mathematically,

$$P_{t+1}^{*} = E_t[P_{t+1} \mid I_t]$$

where P_{t+1}^{*} is expected price for period t + 1

P_{t+1} is market price for period t + 1

I_t is information available at period t

In this hypothesis, expected price is treated as endogenous to the model structure. Therefore, the expected price is expressed as a function of the past price and parameters in the model structure. In the adoptive expectations hypothesis, the expected price is expressed in terms of only the past prices. The rational expectations hypothesis is theoretically satisfactory and attractive. However, its use in empirical studies is rather complex and difficult because of cross-equation restrictions and autocorrelation problems.

B. General Functional Form of Supply Model

A common practical problem in analyzing supply response is the choice of a functional form for econometric estimation. Most studies on supply functions of agricultural products have been made using the two functional forms. First is the linear form in which quantity supplied is assumed to be a linear function of the explanatory variables. The second is the linear-in-logarithms functional form (or logarithmic form) in which all variables are transformed in the logarithmic form.

Since there is no a priori reason for the choice of particular form (linear or logarithmic forms), a choice between the two forms is frequently difficult in empirical studies. The use of either the linear form or logarithmic form in empirical estimation may have some implications that are restrictive or inconsistent from the view of economic theory or actual phenomena. That is, the logarithmic functional form indicates that price elasticity of supply remains constant at any price level. The implication of this constant elasticity may be too restrictive or inconsistent when price fluctuates a lot. On the other hand, the linear form implies that price elasticity is rising and tends to approach unity, if it is less than unity.[1] This implication is inconsistent with the economic theory on the supply elasticity of agricultural products when there is an increase in price. Price elasticity of supply for a specific kind of agricultural product should be, or tends to be, falling rather than rising.

In addition to the linear and double-log form of supply functions, there is a need to examine the functional form for supply function of agricultural products. The works of Box-Cox and Box-Tidwell, on the transformation of variables, facilitate the use of a more general functional form to estimate the relationship between dependent and explanatory variables. Their works show that the linear and logarithmic forms are special cases of general functional form. The purpose of this part

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[1]Let the supply function be: $Q = a + bP$

Then the price elasticity is: $\eta = \frac{P}{Q}\frac{dQ}{dP} = \frac{bP}{a+bP} = \frac{1}{\frac{a}{bP}+1}$

If prices go up, then $\frac{a}{bP}$ gets smaller under positives value of a and b. Thus, η tends to approach unity. Even under negative values of a, η tends to approach unity if price goes up.

is that the transformation of variables, provided by Box-Cox and Box-Tidwell, is applied to the supply relation in order to allow for more flexible functional form.

Instead of the linear or logarithmic functional form, the specification of a single equation supply model with an application of the transformation of Box-Cox and Box-Tidwell is expressed as follows:

$$Q_t(\lambda_o) = \beta_o + \beta_1 X_{1t}(\lambda_1) + \beta_2 X_{2t}(\lambda_2) + \dots + \beta_k X_{kt}(\lambda_k) + U_t \qquad (4.11)$$

where $Q_t(\lambda_o) = \dfrac{Q_t^{\lambda_o} - 1}{\lambda_o}$

and

$$X_{it}(\lambda_i) = \frac{X_{it}^{\lambda_i} - 1}{\lambda_i} \; ; \; i = 1, 2, 3, \dots, k. \qquad (4.12)$$

Q_t is quantity supplied at time t, and X_{it}s are explanatory variables. U_t is disturbance term. Each λ_i is a transformation parameter for each variable to be determined.

Certain a priori restrictions can be imposed on each λ_i of Equation 4.11. Consider the case in which all λ_is are equal to unity. Then, Equation 4.11 becomes a linear form. That is,

$$Q_t - 1 = \beta_o + \beta_1(X_{1t} - 1) + \beta_2(X_{2t} - 1) + \ldots + \beta_k(X_{kt} - 1) + U_t \qquad (4.13)$$

or

$$Q_t = (1 + \beta_o - \beta_1 - \beta_2 - \ldots - \beta_k) + \beta_1 X_{1t} + \beta_2 X_{2t} + \ldots + \beta_k X_{kt} + U_t \qquad (4.14)$$

or

$$Q_t = \beta_o^* + \beta_1 X_{1t} + \beta_2 X_{2t} + \ldots + \beta_k X_{kt} + U_t \qquad (4.15)$$

where $\beta_o^* = (1 + \beta_o) - \sum_{i=1}^{k} \beta_i$

Therefore, the linear functional form is a special case of Equation 4.11 when each λ_i is equal to unity.

Consider the case in which all λ_is are equal to zero. Then, Equation 4.11 reduces to the logarithmic form.[1] That is,

$$\log^{Q_t} = \beta_o + \beta_1 \log^{X_{it}} + \beta_2 \log^{X_{2t}} + \ldots + \beta_k \log^{X_{kt}} + U_t \qquad (4.16)$$

Of course, the transformation parameters can have different values of real numbers to each other. The transformation is valid as long as all

---

[1] If $\lambda = 0$, then the expression $Q_t(\lambda)$ and $X_{it}(\lambda)$s seem to be undeterminate. Note that any finite positive number (e.g., Q_t) can be written as

$$Q_t = e^{\log^{Q_t}}$$

and $e^{\log^{Q_t}}$ can be extended as follows:

$$e^{\log^{Q_t}} = 1 + \log^{Q_t} + \frac{(\log^{Q_t})^2}{2!} + \frac{(\log^{Q_t})^3}{3!} + \ldots$$

Thus,

$$Q_t(\lambda) = \frac{Q_t^{\lambda} - 1}{\lambda} = \frac{1}{\lambda}[e^{\log^{Q_t^{\lambda}}} - 1] = \frac{1}{\lambda}[e^{\lambda \log^{Q_t}} - 1]$$

$$= \frac{1}{\lambda}[1 + \lambda \log^{Q_t} + \frac{(\lambda \log^{Q_t})^2}{2!} + \frac{(\lambda \log^{Q_t})^3}{3!} + \ldots \frac{(\lambda \log^{Q_t})^n}{n!} - 1]$$

$$= \log^{Q_t} + \frac{\lambda(\log^{Q_t})^2}{2!} + \frac{\lambda^2(\log^{Q_t})^3}{3!} + \frac{\lambda^3(\log^{Q_t})^4}{4!}$$

$$+ \ldots \frac{\lambda^{n-1}(\log^{Q_t})^n}{n!}$$

if $\lambda = 0$, then $Q_t(\lambda) = \frac{Q_t^{\lambda} - 1}{\lambda} = \log^{Q_t}$

Similarly, if $\lambda = 0$,

$$\text{then } X_{it}(\lambda) = \frac{X_{it}^{\lambda} - 1}{\lambda} = \log^{X_{it}}; \; i = 1, 2, \ldots, n.$$

λ_is are real numbers because $X_{it}(\lambda_i = 0) = \log^{X_{it}}$. When transformations are made, there can be an infinite number of combinations for each transformation parameter. Thus, Equation 4.11 provides a more general form in which the linear and logarithmic functional forms are special cases. Therefore, the use of Equation 4.11 provides a realistic advantage in analyzing a supply function since no a priori knowledge from the economic theory exists on the functional form of supply.

The elasticity of supply with respect to price (i.e., X_{kt}) can be written[1] as:

$$\eta = \beta_k \left(\frac{X_{kt}^{\lambda_k}}{Q_t^{\lambda_o}} \right) \tag{4.17}$$

The sign of the price elasticity of supply depends on the sign of β_k since Q_t and X_{kt} are non-negative, and since each transformation parameter is a real number. The value of the price elasticity of supply with an increase

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[1]From Equation 4.11 take the total differentiation.

Then $Q_t^{\lambda_o - 1}\, dQ_t = \beta_1 X_{1t}^{\lambda_o - 1}\, dX_{1t} + \beta_2 X_{2t}^{\lambda_2 - 1}\, dX_{2t} + \ldots + \beta_k X_{kt}^{\lambda_k - 1}\, dX_{kt}$

Let $dX_{1t} = dX_{2t} = \ldots = dX_{k-1_t} = 0$

Then $\dfrac{dQ_t}{dX_{kt}} = \beta_k \dfrac{X_{kt}^{\lambda_1 - 1}}{Q_t^{\lambda_o - 1}}$

Thus, $\eta = \dfrac{X_{kt}}{Q_t} \dfrac{dQ_t}{dX_{kt}} = \beta_k \left(\dfrac{X_{kt}^{\lambda k}}{Q_t^{\lambda_o}} \right)$.

in X_{kt} can increase, or decrese, depending on the value of Q_t and transformation parameters. When all λ_is are equal, price elasticity of supply reduces to:

$$\eta = \beta_k \left(\frac{X_{kt}}{Q_t}\right)^{\lambda} \tag{4.18}$$

In this case, the value of the price elasticity of supply with an increase in X_{kt} can be changed, depending on the relative change of Q_t and X_{kt}, and the value of λ. When all λ_is are equal to one (linear supply function), the elasticity becomes:

$$\eta = \beta_k \frac{X_{kt}}{Q_t} = \frac{\beta_k X_{kt}}{\beta_o^* + \beta_1 X_{1t} + \beta_2 X_{2t} + \ldots + \beta_k X_{kt}} \tag{4.19}$$

Therefore, the elasticity tends toward unity as X_{kt} increases, while other variables remain constant. When all λ_is are equal to zero (logarithmic supply function), the elasticity becomes:

$$\eta = \beta_k \left(\frac{X_{kt}}{Q_t}\right)^{o} = \beta_k \tag{4.20}$$

Therefore, the elasticity becomes constant, independent of the value of Q_t, X_{kt}, and λ_is.

Another advantage of the use of the transformation in Equation 4.11 over either the linear or logarithmic functional form in an analysis of supply model is to show a cross effect between explanatory variables; the effect of a change in particular input price on the supply elasticity, the effect of a change in technology on the producer's response, and so on. Let the supply curve be:

$$Q_t = f(P_t) \tag{4.21}$$

where Q_t is quantity supplied at time t, and

P_t is price at t.

This equation can be extended by adding a variable representing a technological change. It is assumed for simplicity that quantity supplied is a function of current price and technology. Then, the supply function is:

$$Q_t = f(P_t, T_t) \tag{4.22}$$

where T_t is technological index in time t.

Since technology is an important factor in an analysis of supply function, it is supposed that the producers' response to price, price elasticity of supply, is affected by technological change over time. However, when either the linear or logarithmic form of supply function is employed, the effect of a technological change on supply elasticity seems to be unreasonable.

Consider the case of logarithmic supply model. Let the supply function be:

$$\log Q_t = \beta_o + \beta_1 \log P_t + \beta_2 \log T_t \tag{4.23}$$

Then, the supply elasticity is:

$$\eta = \beta_1 \text{ (= constant)} \tag{4.24}$$

Then, the effect of a change in technology on the supply elasticity is:

$$\frac{\partial \eta}{\partial T} = 0 \tag{4.25}$$

Therefore, the change in technology does not alter supply elasticity. In other words, the effect of a change in elasticity with respect to change in technology is not available. Consider the case of linear supply model. Let the supply function be:

$$Q_t = \beta_o + \beta_1 P_t + \beta_2 T_t \tag{4.26}$$

Then, the supply elasticity is:

$$\eta = \frac{\beta_1 P_t}{Q_t} = \frac{\beta_1 P_t}{\beta_o + \beta_1 P_t + \beta_2 T_t} \tag{4.27}$$

Then, the effect of a change in technology on the supply elasticity is:

$$\frac{\partial \eta}{\partial T} = - \frac{\beta_1 \beta_2 P_t}{Q_t^{\ 2}} = - \frac{\beta_1 \beta_2 P_t}{(\beta_o + \beta_1 P_t + \beta_2 T_t)^2} \tag{4.28}$$

Since β_1 and β_2 are assumed to be positive, the sign $(\frac{\partial \eta}{\partial T})$ is negative. Therefore, it can be concluded with the linear supply model that an advance in technology reduces the producers' response to price. Since technological change has an obvious effect on the supply elasticity, the linear functional form appears to be better specification than the logarithmic functional form when a focus is to find a change in the producers' response with respect to change in other variables such as technology or input prices. However, since the linear form always gives a negative effect of technological change on the producers' response to price, it may be unreasonable, because producers of some products can be more responsive to price with an improvement of technology over time. Thus, it would be necessary to consider a general functional form in Equation 4.11 to show a more flexible effect of change in technology on the supply elasticity.

Let the supply function of an application of the transformation of variables in Equations 4.11 and 4.12 be:

$$Q_t(\lambda_o) = \beta_o + \beta_1 P_t(\lambda_1) + \beta_2 T_t(\lambda_2) \tag{4.29}$$

The supply elasticity is:

$$\eta = \beta_1 \frac{P_t^{\lambda_1}}{Q_t^{\lambda_o}} \tag{4.30}$$

Then, the effect of a change in the elasticity with respect to a technological change is:

$$\frac{\partial \eta}{\partial T} = -\lambda_o \eta \, \beta_2 \frac{T_t^{\lambda_2 - 1}}{Q_t^{\lambda_o}} \tag{4.31}$$

Since the supply elasticity is expected to be positive and technology has a positive effect on output supply ($\beta_2 > 0$), the sign of $(\frac{\partial \eta}{\partial T})$ depends on the value of λ_o.

That is,

$$\text{sign}\left(\frac{\partial\eta}{\partial T}\right) = \text{sign}\,(-\lambda_o) \tag{4.32}$$

Therefore, the supply elasticity can increase, or decrease, or be unchanged with an advance of technology, depending on the sign of transformation parameter of the dependent variable (i.e., λ_o). For example, with a positive value of λ_o, an improvement of technology will decrease the supply elasticity. This means that producers become less responsive to price and the supply curve becomes steeper over technological change. Under a negative value of λ_o, the supply elasticity increases with an advance of technology. This implies that producers become more responsive to price and the supply curve becomes flatter with technological advance. If λ_o is zero, technology does not alter the elasticity as shown in the logarithmic model.[1] Therefore, a supply model with an application of Box-Cox and Box-Tidwell transformation would give a more flexible answer to the question of effect of technology on the producers' response to price.

If all λ_is are equal, then Equation 4.31 becomes:

$$\frac{\partial\eta}{\partial T} = -\lambda\,\eta\,\beta_2\,\frac{T_t^{\lambda-1}}{Q_t^{\lambda}} \tag{4.33}$$

Then,

$$\text{sign}\left(\frac{\partial\eta}{\partial T}\right) = \text{sign}\,(-\lambda) \tag{4.34}$$

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[1]It should be noted that, even though the conclusion with $\lambda_o = 0$ is the same as that of logarithmic model, their functional forms are different. With zero of λ_o the transformation parameters of independent variables can have values different from zero.

If all λ_is are equal to unity, then Equation 4.31 becomes:

$$\frac{\partial\eta}{\partial T} = -\eta\ \beta_2 \frac{T_t^{\ o}}{Q_t} = -\frac{\beta_1\beta_2 P_t}{Q_t^{\ 2}} \tag{4.35}$$

Then, sign $(\frac{\partial\eta}{\partial T}) < 0$. (4.36)

If all λ_is are equal to zero then Equation 4.31 becomes:

$$(\frac{\partial\eta}{\partial T}) = 0 \tag{4.37}$$

Similarly, the effect of a time element (or trend) on the supply elasticity can be considered by adding a trend variable to the basic supply model. Cross price effects can also be discussed by adding a price of competing product(s).

Providing that the general functional form is of better specification, the next problem is an estimation of the transformation parameters with regression coefficients in empirical work.

For the estimation procedure, suppose that the disturbance term in Equation 4.11 is normally and independently distributed with a zero mean and constant variance under appropriate transformation.

Using the maximum likelihood approach, the likelihood function is:

$$L(\beta,\ \sigma^2,\ \lambda) = \frac{1}{(2\pi)^{\frac{N}{2}}\ \sigma^N} \exp\left[\frac{\sum_{i=1}^{n}[Q_t(\lambda_o) - \beta_o - \beta_1 X_{1t}(\lambda_1)}{2\sigma^2}\right.$$

$$\left.\frac{- \dots - \beta_k X_{kt}(\lambda_k)]}{2\sigma^2}\right] \cdot J \tag{4.38}$$

where β is the vector $(\beta_o, \beta_1, \beta_2, \ldots, \beta_k)$,

λ is the vector $(\lambda_o, \lambda_1, \lambda_2, \ldots, \lambda_k)$,

σ^2 is variance of disturbance term, and

J is the Jacobian of the transformation on the dependent variable, or

$$J = \prod_{t=1}^{N} \left| \frac{dQ_t(\lambda_o)}{dQ_t} \right| = \prod_{t=1}^{N} Q_t^{\lambda_o - 1} \tag{4.39}$$

The logarithm of the likelihood function (e.g., logarithmic likelihood function) is maximized with respect to β, σ^2, given λ. The maximum likelihood estimate of σ^2 for a given λ, $\hat{\sigma}^2(\lambda)$, is then the estimated variance of the disturbances of the regression $Q_t(\lambda_o)$ on the $X_{it}(\lambda_i)$s. Taking logs and replacing σ^2 by $\hat{\sigma}^2(\lambda)$ in the maximized likelihood function, the maximum log likelihood $[L_{max}(\lambda)]$ is, except for a constant term,

$$L_{max}(\lambda) = - \frac{N}{2} \log \hat{\sigma}^2 (\lambda) + (\lambda_o - 1) \sum_{t=1}^{N} \log Q_t \tag{4.40}$$

It is possible to choose alternative values of each λ_is over the whole parameter space to maximize Equation 4.40.

There are two approaches in the estimation procedure of Equation 4.40. The first approach is to transform the data so that $Q_t(\lambda_o)$ is regressed on $X_{it}(\lambda_i)$s, using ordinary least squares. Then a search is made by changing the value of λ_is so as to maximize Equation 4.40.

Another approach is to maximize the log likelihood function in 4.40 by gradient methods that converge on the value of the optimal λ_is. That is, the maximum likelihood estimates are obtained by searching over a grid of different values of each λ_is.

So far, an advantage of the use of the general functional form with transformations of variables was discussed with a comparison over the linear and logarithmic functional forms. Unfortunately, there is no linkage between economic theory and choice of functional form. Numerous attempts have been made in empirical analyses of economic behavior to find a better functional form in order to satisfy their own purposes. A common technique in statistical estimation of economic phenomena is choosing either the linear or logarithmic functional form. However, both are special cases of the general functional form as shown in Equation 4.11. The transformation of variables provided by Box-Cox and Box-Tidwell is a powerful technique in empirical studies when economic theory does not suggest a functional form.

C. Specification of Irreversible Supply Function

The property of irreversibility of the supply function has been generally ignored in empirical studies. The previous section dealt only with the method of specifying the reversible supply function. Therefore, the procedure of specifying the irreversible supply model will be presented in this section.

The question of specifying and estimating an irreversible function has arisen most frequently in studies of the agriculturaly supply function. The empirical estimation of the supply curve with irreversible characteristics was pioneered by Tweeten and Quance, and followed by Wolffram, Houck, Traill et al., and others.

Tweeten and Quance [53] treated the irreversible nature of supply curve to price change by splitting the price variable into two variables, one for increasing prices and another for decreasing prices. When P is a price for a specified period of decreasing or increasing prices, it is the actual observed value for the specified period and has a zero value for other periods over the sample period.

Mathematically,

$$P_t^{I} = \begin{cases} P_t & \text{if } P_t \geq P_{t-1} \\ 0 & \text{otherwise} \end{cases}$$

$$P_t^{D} = \begin{cases} P_t & \text{if } P_t < P_{t-1} \\ 0 & \text{otherwise} \end{cases}$$

where superscripts I and D stand for the increasing and decreasing phases, respectively. Assuming for simplicity that current supply is a function of current price,

the reversible supply function is: $Q_t = \alpha_o + \alpha_1 P_t$

the irreversible supply function is: $Q_t = \alpha_o + \alpha_1 P_t^{I} + \alpha_2 P_t^{D}$

Wolffram [64] pointed out that the Tweeten and Quance's method for estimating the irreversible function was mathematically incorrect and leads to estimates of the two price parameters that are not statistically significantly different. After Wolffram's criticism, Tweeten and Quance generally endorsed the Wolffram's method of estimating the irreversible function. Wolffram's method of splitting the independent variable into an increasing and a decreasing phase is based on the calculation of the first differences of the observation values of the independent variables being split. The Wolffram's procedure of segmenting the price variable into P^I for increasing prices and P^D for decreasing prices depends on the accumulated sum of the first differences ($\Delta P = P_t - P_{t-1}$). P^I for increasing prices is obtained in the following way:

$$
\begin{aligned}
P_o^I &= P_o \\
P_1^I &= P_o + k(P_1 - P_o) \\
P_2^I &= P_1^I + k\ (P_2 - P_1) \\
P_3^I &= P_2^I + k\ (P_3 - P_2) \\
&\vdots \\
P_t^I &= P_{t-1}^I + k(P_t - P_{t-1})
\end{aligned}
$$

where P_o is initial observation of price variable over the sample period

$$
\begin{aligned}
k &= 1 \text{ if } P_t - P_{t-1} > 0 \\
& 0 \text{ if } P_t - P_{t+1} < 0
\end{aligned}
$$

Similarly, starting from $\Delta P_t = P_t - P_{t-1} < 0$, P^D for decreasing prices is obtained in the following way:

$$P_o^D = P_o$$

$$P_1^D = P_o + |(1 - k)(P_1 - P_o)|$$

$$P_2^D = P_1^D + |(1 - k)(P_2 - P_1)|$$

$$P_3^D = P_2^D + |(1 - k)(P_3 - P_2)|$$

$$\vdots$$

$$P_t^D = P_{t-1}^D + |(1 - k)(P_t - P_{t-1})|$$

Therefore, the (n - 1) first differences over n observations are used to form two segmented variables for rising and falling prices. The P^I variable is formed by adding the positive first difference ($\Delta P = P_t - P_{t-1} > 0$) to the initial value, which can be any positive number. Wolffram employed a first observed value of price for the identification of the initial value. Similarly, the P^D variable is formed by adding the absolute value of the negative first difference ($\Delta P = P_t - P_{t-1} < 0$) to the initial value. That is, a change in price from period to period is added to the price of initial period to form a split variable. The value of split-price variables is either increasing or stationary: (1) at least one variable is increasing if there is a change in price from period to period, and (2) the two variables are stationary under no change in price from period to period. Using this procedure for splitting variables, the estimated results of coefficients for split variables are expected to differ in signs. Wolffram provided his estimated results with his hypothesized data, supporting irreversibilities that one unit increase in an independent variable from period to period has a different absolute effect on the dependent variable than one unit decrease in an independent variable does.

Houck [24] suggested an alternative approach to specifying the irreversible function. His method is basically consistent with the Wolffram's technique, but the difference between the two techniques is in the first observation which has no independent explaining power. Houck's method dropped the first observation for segmentation, while Wolffram's method adds the first difference to the first observation. Houck's method of segmenting an independent variable is as follows:

Let the irreversible reaction of output supply to changing price be expressed as:

$$\Delta Q_t = a_o + a_1(\Delta P_t^{\,I}) + a_2(\Delta P_t^{\,D})$$

where $\Delta Q_t = Q_t - Q_{t-1}$

$$\Delta P_t^{\,I} = P_t - P_{t-1} \quad \begin{cases} \text{if } P_t > P_{t-1} \\ 0 \quad \text{otherwise} \end{cases}$$

$$\Delta P_t^{\,D} = P_t - P_{t-1} \quad \begin{cases} \text{if } P_t < P_{t-1} \\ 0 \quad \text{otherwise} \end{cases}$$

Since the difference between the current and the initial period of dependent variable, Q, is the sum of the period-to-period changes over the sample period,

$$Q_t - Q_o = \sum_{t=1}^{n} \Delta Q_t$$

Then,

$$\sum_{t=1}^{n} \Delta Q_t = \Sigma[a_o + a_1 \Delta P_t^{\,I} + a_2 \Delta P_t^{\,D}]$$

$$= \sum_{t=1}^{n} a_o + a_1 \sum_{t=1}^{n} \Delta P_t^{\,I} + a_2 \sum_{t=1}^{n} \Delta P_t^{\,D}$$

or

$$Q_t^{*} = a_o^{*} + a_1 I^{*} + a_2 D^{*}$$

where $Q_t^{*} = \sum_{t=1}^{n} \Delta Q_t = Q_t - Q_o$ is the difference between the current and initial output,

$a_o^{*} = \sum_{t=1}^{n} a_o = na_o$,

$I^{*} = \sum_{t=1}^{n} \Delta P_t^{\,I}$ is the sum of period-to-period increase in price from its initial value up to time t, and

$D^{*} = \sum_{t=1}^{n} \Delta P_t^{\,D}$ is the sum of period-to-period decrease in price from its initial value up to time t.

As shown above, Houck's method for segmenting an independent variable is also based on the calculation of the first differences of the independent variable. Another distinction between the two studies is that Houck's method resulted in positive signs of the estimates of D^{*}, while Wolffram's method resulted in negative signs.

Traill et al. [52] suggested their own method to specify the irreversible supply functions. Their method is also based on the calculation of the first difference of an independent variable from period to period, but focuses on the ratchet effect. They argued,

> For empirical purposes, it is assumed that the elastic portion of the curve in response to falling prices is unimportant (i.e., ...). Then, following a fall in price and movement down the inelastic portion of the supply function, price must regain its previous high level before response becomes elastic. We thus obtain a ratchet model. ...; when price rises but remains below its previous high level, the amount of the price change is added to the price fall series rather than to the price rise series [52, pp. 528-529].

Their method is based on the Wolffram's technique, but the difference is where to add the first difference of price variable. Thus, they called their method "Modified Wolffram method." However, their method seems to be more theoretical.

The use of the spline function in specifying the irreversible supply function was suggested by Groenewegen [15]. He proposed two types of specification; one is for complete irreversibilities, without consideration of ratchet effect, and another for partial irreversibilities, with consideration of ratchet effect. His approach is to show that the spline function is flexible in specifying the irreversible supply function, but his method is rather complex, when compared with the methods mentioned by Wolffram, Houck, and Traill et al.

The empirical studies by Wolffram, Houck, and Traill et al. concerning the estimation of the irreversible supply function were made in linear functional form, imposing a restriction of the functional form on the reversible supply function. In this study, the irreversible nature of supply function will be estimated and tested employing a general functional form, without imposing any restrictions on the reversible supply function.

V. SPECIFICATION OF BROILER SUPPLY MODEL

The theoretical procedure of deriving a supply function provides ideas for selecting variables to be employed in the broiler supply function. Due to the fact that the broiler industry differs in terms of final products, and that broiler production is highly specialized, the competitive enterprises (or products) will be excluded in the analysis of the broiler supply function. In other words, broiler supply (or production) will mainly depend on the profitability of its production. The quantity of broilers produced is directly associated with factors which affect the raising of broiler chicks. The first things to be considered when building the broiler supply model are the components of production costs, or what kind of factors are used in what proportions in the process of production? This is the step necessary to understand the production decisions of a broiler-growing farm.

A. Components of Inputs

Table 5.1 represents the changes in relative importance of production input costs for broilers between the mid-1960s and the mid-1970s. As shown in Table 5.1, feed is the largest and most important input in broiler production. Precisely formulated complete rations are generally used in the production process. The mixed feeds are often varied by age of birds, sex, season, climate, and typically programmed to use least-cost formulations. The relative portion of feed cost over total cost

Table 5.1. Relative importance of production input costs, United States, selected periods[a]

	Mid-1960s	Mid-1970s
Feed	64	73
Chicks	18	12
Labor/management	7	6.5
Energy	2	2
Other variables	4	2
Overhead	5	4.5
Total	100%	100%

[a]Source: [44].

increased from 64 percent in the mid-1960s to 73 percent in the mid-1970s. Since feed cost takes into account more than 60 percent of the total production cost, broiler production depends mainly on the amount of feed used in the industry. Table 5.2 shows the annual production cost and relative share of the feed cost over total production cost of commercial broiler production during the period 1955-1976.

The cost of chicks is the next largest cost item, representing about 18 percent of total production cost in the mid-1960s and 12 percent in the mid-1970s. The relative importance of chick cost declined during the last two decades. Since baby chicks are a very necessary input in broiler production, it is hypothesized that the higher the price of chicks, the lower is the quantity demanded by the broiler producers. Feed and baby chicks accounted for about four-fifths of the total production cost, making them the two main cost items. Hence, the prices of feed and broiler-type baby chicks are chosen as variables to be included in the broiler

Table 5.2. Commercial broilers: annual production costs per pound in liveweights: 1955-1976[a]

Year	Feed (cents)	Other (cents)	Total (cents)	Feed/total (percentages)
1955	13.1	7.4	20.5	63.95
1956	12.3	6.7	19.0	64.74
1957	11.9	6.3	18.2	65.38
1958	11.6	6.0	17.6	65.91
1959	11.0	5.7	16.7	65.87
1960	10.3	5.4	15.7	65.61
1961	10.0	5.1	15.1	66.23
1962	9.9	4.9	14.8	66.89
1963	10.1	4.7	14.8	68.24
1964	10.0	4.5	14.5	68.97
1965	9.8	4.7	14.5	67.57
1966	9.8	4.9	14.7	66.67
1967	9.1	5.0	14.1	64.54
1968	8.4	5.1	13.5	62.22
1969	8.5	5.3	13.8	61.59
1970	8.8	5.4	14.2	61.97
1971	9.0	5.3	14.3	62.94
1972	9.0	5.3	14.3	62.94
1973	16.2	5.9	22.1	73.30
1974	15.9	6.3	22.0	72.27
1975	15.1	6.2	21.3	70.89
1976	15.0	6.3	21.3	70.42

[a]Source: [3].

supply model.

Even if labor is a necessary factor in the production process, wages in the broiler industry, representing labor cost, will not be included in this study, since its share is relatively small and declining. During the process of specialization, many mechanical devices have become available for reducing the number of hours of labor required per unit of broilers raised. Therefore, labor efficiency becomes more important in broiler production rather than the amount of labor hired.

The number of farms producing broilers have become fewer, dropping from about 42,000 in 1959 to about 33,000 in 1974, while output per farm increased from 33,600 broilers in 1959 to 72,400 broilers in 1974 [3, p. 2]. This demonstrates that production units have become larger. In the long run, the response of production means the addition of or shutdown of production facilities. The cost of capital for production facilities should be considered as one of the important factors in the production decision for the period of output expansion. Broiler production is becoming more concentrated in larger specialized units, and has continuously increased. With an increase in the size of the production unit, the broiler industry has experienced an increased mechanization with high specialization in the production pattern. More environmentally controlled housing, equipment and machinery have tended to increase capital investment, which is related to the fixed cost in the broiler industry. The capital investment in land, buildings and equipment is the main fixed factor in broiler production. The depreciation on buildings and equipment is the largest fixed cost item since investment in land is constant. Therefore, the capital investment for broiler production (e.g., buildings and equipment, except land) is determined by the broiler capacity or the number of live broilers to be raised. This implies that the number of live broilers for a specified period of time (e.g., per year) can be considered as a proxy variable for capital investment. Since the number of live broilers (or flock size) is determined by the amount of the purchase of the broiler-type baby chicks, there must be a perfect correlation between flock size and purchase of baby chicks. Therefore, there should be a high correlation between the capital investment and the purchase of baby chicks. Based on this reasoning, a variable representing directly fixed cost items will not be included in this study, because the variable for baby chicks is already chosen. This can be justified on grounds that fixed cost accounts for a relatively small portion of the production cost per unit of broilers. Thus, it is assumed that the broiler supply is a function of the broiler price, feed price and baby chick price. However, there are still problems in formulating a broiler supply function, because the broiler industry has been greatly affected by technological progress and no variable for technological change is selected.

B. Feed Conversion Ratio in the Broiler Industry

As discussed in Chapter 3, technological change alters the price-quantity relationship of supply, and there are difficulties in measuring technological change. Since the broiler industry has the highest growth rate in the meat industry, the growth should be explained largely by a technological change. To find a proper variable for technological progress in the broiler industry, we will first discuss the kinds of technology that has been used in agriculture.

In agriculture, technology can be classified into two categories:

mechanical technology as labor-saving and biological technology as land-saving. Hayami and Ruttan [19, p. 44] say, "Mechanical technology is designed to facilitate the substitution of power and machinery for labor .... Biological technology is designed to facilitate the substitution of labor and/or industrial inputs for land." Technological change depends on a series of simultaneous progressions of both mechanical and biological technology.

Mechanical technology in broiler production is realized in the output-labor ratio or average productivity of labor. An increase in average productivity of labor or labor efficiency has been an important factor for the growth in the broiler industry. Man hours per 1,000 broilers produced decreased from 250 in the 1940s, to 26 in 1965, and to 15 in 1969 as a result of increased mechanization and more efficient layouts [13, p. 39 and 59, p. 15]. Many kinds of mechanical equipment such as automatic feeding and watering systems have contributed to the reduction in the number of hours required for each 1,000 broilers raised. However, the increase in labor productivity is not likely to be the major factor of the growth of broiler production, since the share of labor and management cost over total cost has been less than 10 percent during the last two decades.

The technological change for the growth of broiler production is more likely to be explained by biological technology. In broiler production biological technology includes the following aspects: (1) nutrition, (2) breeding, (3) disease control, (4) environmental control, etc. Advanced research in nutrition and feeding led to improved formula feeds. The addition of antibiotics to feed is an important factor in maintaining healthy broilers and in improving feed efficiency. Improved breeding through the successful production of high quality baby chicks increased the production efficiency, and also contributed to the production of desired meats. The advanced method of controlling disease contributed to reduce technological uncertainty of production. Environmentally controlled housing with the regulation of light and temperature contributed to better feed conversion, especially during the winter season. The progress of biological technology has contributed to a remarkable increase in output per unit of feed. Each 100 pounds of feed produced 18.9 pounds of live broiler in 1935, 33.9 pounds in 1959, and 47.6 pounds in 1980. Since feed has been the largest cost item, accounting for more than 60 percent of total cost, it is clear that broiler farms have responded to a change in feed efficiency. It is assumed that biological technology realized in the broiler-feed conversion ratio has been the main source of the rapid growth of broiler production.

However, it is obvious that biological technology has been reinforced by mechanical technology and progressive management systems. That is, mechanical technology and management systems have also contributed to feed efficiency, even if their effects are not individually measurable. Due to an increase in feed efficiency, the amount of feed and other production factors needed to produce a pound of meat has decreased, which has been followed by a decrease in production cost. This is why the feed conversion ratio is chosen as a variable for technological change in broiler production. Moreover, it is generally agreed that the feed conversion ratio can be considered as a technological indicator in broiler production.

However, there is still a problem in using the broiler-feed conversion ratio as a measure of the net effect of technological change, because the input-output ratio can be affected by a change in the input-output price ratio (or broiler-feed price ratio) as well as a change in the production function. For the measure of net effect of technological change, it seems better to derive the trend of the feed conversion ratio. Here it is hypothesized that the trend of the broiler feed conversion ratio follows a logistic curve, which fits well to the phenomenon of biological growth (i.e., population growth). This can be justified on the grounds that biological technology has greatly contributed to an increase in feed efficiency in broiler production. The logistic curve is defined as follows:

$$FCR(t) = \frac{a}{1 + b\,e^{-ct}} \tag{5.1}$$

where FCR(t) is broiler feed conversion rate,

t is time, and

a, b, and c are parameters to be determined.

Equation 5.1 is an S-shaped curve with a minimum value of $\frac{a}{1+b}$ and a maximum value of a under the positive values of a, b and c. The properties of the logistic curve in Equation 5.1 provide a logical basis that works well to derive the trend of the feed conversion ratio. That is, there must be an upper limit in the broiler-feed conversion ratio. Even under the high speed technology, 100 pounds of feed cannot be converted into 100 pounds of meat in broiler production. There is also a lower limit using no advanced feeding technique. In other words, the broiler is growing, even if it is not healthy, while it is being fed. Moreover, the broiler feed conversion ratio increased slowly during the early stages of commercial broiler production, but increased rapidly along with the continuous research in broiler products, and is expected to be slowed down as it approaches the upper limit. This is why the logistic function in Equation 5.1 is employed to derive the trend of the broiler feed conversion ratio.

For estimation purposes, 18 pounds and 67 pounds of broilers in liveweight per 100 pounds of feed are chosen as a lower limit and an upper limit, respectively, of the broiler-feed conversion ratio, based on Hayami's [18] work and the information provided by a poultry scientist[1] at Iowa State University. Ordinary least squares technique is applied to estimate Equation 5.1 after transforming the equation into logarithmic form.

The data for the broiler feed conversion ratio are available for the

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[1]Personal talks with Dr. William Owings at Poultry Science confirmed that the 67 pounds of the feed conversion ratio is still a target in broiler production at the national average level.

period 1933 through 1971 and the year 1980[1], but it is not available for 1972 through 1979. Therefore, the broiler-feed conversion ratio for 1972 to 1979 was first estimated, based on the available data. The estimated equation is:

$$FCR(t) = 18 + \frac{31}{1 + 28.356974\, e^{-0.132755t}} \tag{5.2}$$

Equation 5.2, with a lower limit of 18 and an upper limit of 49, gives a feed conversion ratio of 47.6 for year 1980, which is the actual value in 1980. Then, the logistic curve is again estimated, using the data for the period 1933 to 1980. The estimated equation is:

$$FCR(t) = 18 + \frac{49}{1 + 28.980552\, e^{-0.091084t}} \tag{5.3}$$

Equation 5.3, with a lower limit of 18 and an upper limit of 67 is used to generate a trend of net effect of technological change at an annual and quarterly basis.

Table 5.3 shows the actual observations and estimated values of the broiler-feed conversion ratio for the period of 1933 to 1980 on an annual basis, and estimated values on a quarterly basis for 1959 to 1980.

C. Model Building

Consideration of the production process in the broiler industry should be given in order to understand broiler supply. The stages of

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[1]Personal correspondence with Dr. Allen Baker in U.S.D.A. provides the value of feed conversion ratio in 1980 that 2.1 pounds of feed is used to produce one pound of broiler in liveweight.

Table 5.3. Broiler-feed conversion ratio as a technological indicator: actual observations and estimated values[a,b]

Year	t = time	Actual observation	Estimated value	Quarter	Estimated value
1933	1	18.9	19.8		
1934	2	20.5	19.9		
1935	3	18.9	20.1		
1936	4	20.7	20.3		
1937	5	20.0	20.5		
1938	6	21.5	20.8		
1939	7	20.8	21.0		
1940	8	20.4	21.3		
1941	9	21.5	21.6		
1942	10	20.7	21.9		
1943	11	22.2	22.2		
1944	12	22.3	22.6		
1945	13	21.8	23.0		
1946	14	22.3	23.4		
1947	15	23.0	23.8		
1948	16	24.4	24.3		
1949	17	26.2	24.8		
1950	18	26.7	25.4		
1951	19	27.3	26.0		
1952	20	27.9	26.6		
1953	21	28.5	27.3		
1954	22	29.2	28.0		
1955	23	31.5	28.7		
1956	24	32.0	28.5		
1957	25	33.9	30.3		
1958	26	35.7	31.2		
1959	27	37.7	32.1		

[a]Values expressed in pounds.

[b]Source: [18] and [56].

Table 5.3. continued

Year	t = time	Actual observation	Estimated value	Quarter	Estimated value
1958	26	35.7	31.2	I	
				II	
				III	
				IV	
1959	27	37.7	32.1	I	32.1
				II	32.3
				III	32.6
				IV	32.8
1960	28	39.8	33.0	I	33.0
				II	33.3
				III	33.5
				IV	33.7
1961	29	41.3	34.0	I	34.0
				II	34.2
				III	34.5
				IV	34.7
1962	30	39.7	35.0	I	35.0
				II	35.2
				III	35.5
				IV	35.7
1963	31	40.0	36.0	I	36.0
				II	36.3
				III	36.5
				IV	36.8
1964	32	40.2	37.1	I	37.1
				II	37.3
				III	37.6
				IV	37.9
1965	33	42.4	38.1	I	38.1
				II	38.4
				III	38.7
				IV	38.9

Table 5.3. continued

Year	t = time	Actual observation	Estimated value	Quarter	Estimated value
1966	34	39.2	39.2	I	39.2
				II	39.5
				III	39.8
				IV	40.0
1967	35	39.1	40.3	I	40.3
				II	40.6
				III	40.9
				IV	41.1
1968	36	40.8	41.4	I	41.4
				II	41.7
				III	42.0
				IV	42.3
1969	37	43.7	42.5	I	42.5
				II	42.8
				III	43.1
				IV	43.4
1970	38	44.6	43.7	I	43.7
				II	43.9
				III	44.2
				IV	44.5
1971	39	44.6	44.8	I	44.8
				II	45.0
				III	45.3
				IV	45.6
1972	40	45.2	45.9	I	45.9
				II	46.1
				III	46.4
				IV	46.7
1973	41	45.6	47.0	I	47.0
				II	47.2
				III	47.5
				IV	47.8

Table 5.3. continued

Year	t = time	Actual observation	Estimated value	Quarter	Estimated value
1974	42	46.0	48.0	I	48.0
				II	48.3
				III	48.6
				IV	48.8
1975	43	46.3	49.1	I	49.1
				II	49.3
				III	49.6
				IV	49.8
1976	44	46.6	50.1	I	50.1
				II	50.3
				III	50.6
				IV	50.8
1977	45	46.9	51.1	I	51.1
				II	51.3
				III	51.6
				IV	51.8
1978	46	47.2	52.1	I	52.1
				II	52.3
				III	52.5
				IV	52.8
1979	47	47.4	53.0	I	53.0
				II	53.2
				III	53.4
				IV	53.7
1980	48	47.6	53.9	I	53.9
				II	54.1
				III	54.3
				IV	54.5

broiler production and the time required for each stage are shown in Figure 5.1. Each stage in the figure is very important in understanding and specifying the broiler supply model.

The successful production of high quality chicks begins with the breeder. Chicks used for production of eggs or poultry meat should be derived from breeding flocks on the basis of desired characteristics of egg or meat production. The breeders should be well-maintained under desirable conditions.

Testing, performed by official state agencies, refers to the detection of pullorum and fowl typhoid diseases. The pullorum disease is spread vertically from infected hens to chicks. Infected hens lay eggs containing the infectious organism, and newly hatched chicks will be infected with the disease. Chicks hatched from infected eggs have a high mortality rate. Also, chicks hatched from non-infected eggs may become infected in the incubator by horizontal transmission from infected chicks.

Fowl typhoid is similar to that of pullorum. The purpose of the testing is to eliminate infected breeders from flocks. There are two tests in different stages of production: testing of all hens before introduction in the primary breeder flock and testing of a part of the hens before introduction in the hatchery supply flock.

In the hatching stage, the number of chicks produced by commercial hatcheries is measured. There are two hatchings: hatching of the eggs coming from the breeder flock and hatching of the eggs produced by the hatchery supply flock.

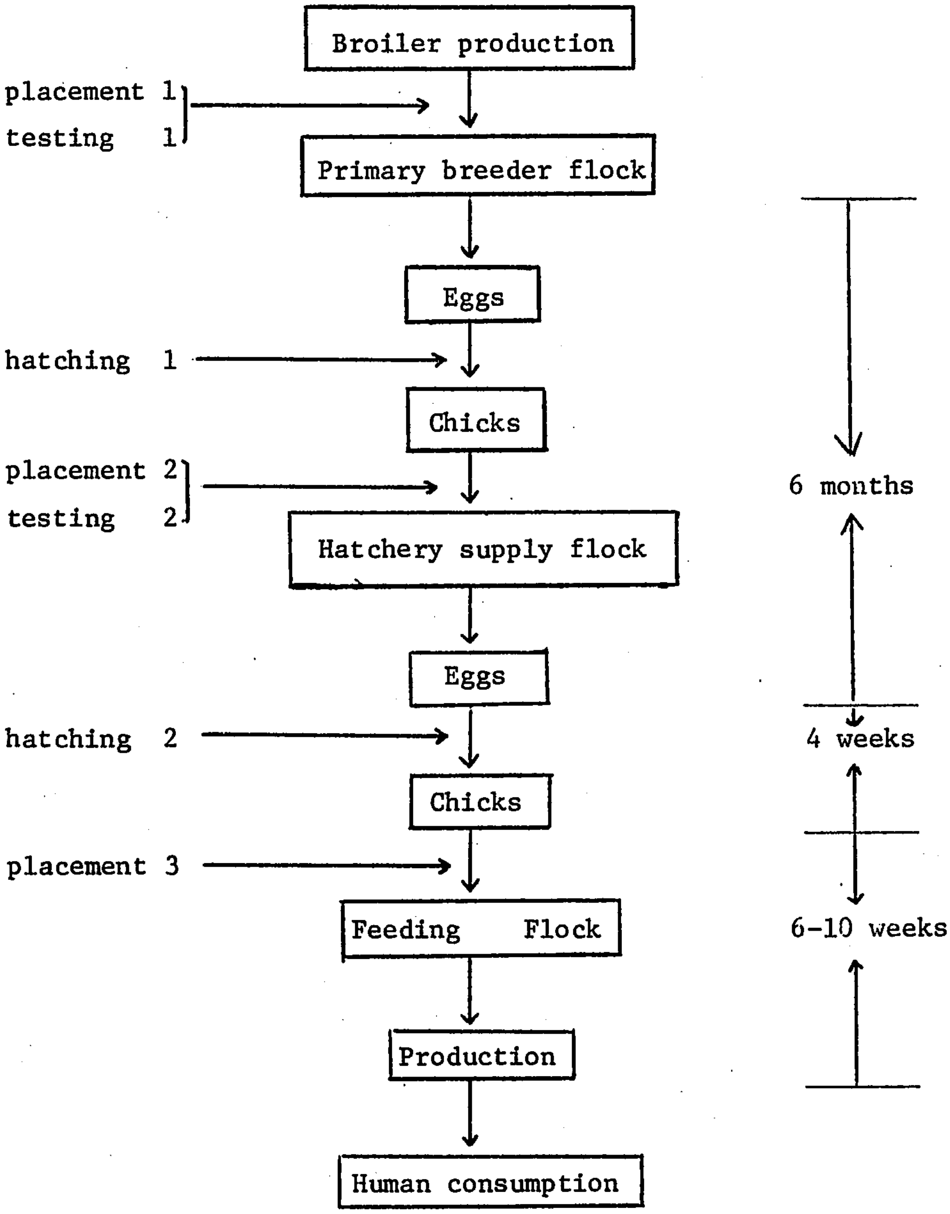

Figure 5.1. Stages in broiler production

Placement refers to the placement of hatched chicks. There are three placements: placement in the primary breeder flock, placement in the hatchery supply flock and placement in the feeding flock. The thing to note is that the hatchery supply flock is much larger than the primary breeder flock. Hence, most of the reported hatching is the hatching of eggs produced by the hatchery supply flock.

Finding a proper time lag in production is very important because time plays a crucial role in each stage of production due to a biological reason. For example, about 6 months are required to get more eggs from the placement of chicks in the hatchery supply flock. This means that it takes about 6 months to substantially increase production of eggs to be provided to the broiler growers, since an increase in broiler hatching requires placement of more chicks in the hatchery supply flock. About 4 weeks are required between the shipment of eggs to the hatchery and the placement of chicks in the broiler-growing farms. About 7-10 weeks are required to grow baby chicks to broilers of slaughter weight. Thus, the total time of broiler production is about 9 months.

There are normally different types of adjustments to changing economic conditions in each stage of production. Egg production in the hatchery supply flock can be changed by adjusting quality and quantity of feed fed, and length of time for birds in the hatchery supply flock, and so on. A production adjustment can be made from the placement of baby chicks with the broiler growers through the broiler grow-out stage. At this stage production cannot be significantly increased, but can be decreased quickly in response to unfavorable market conditions.

Considerations of production period and adjustments in each stage demonstrate that a quarterly supply model could be well-defined to explain the broiler supply structure. The production period of a broiler is relatively short compared with other agricultural products. Broiler production varies seasonally, even if broilers are grown in all seasons. There are significant variations in price within a span of a year. Under these circumstances a quarterly model can provide more information about the broiler supply structure than a model with annual data can. Therefore, a quarterly model will be employed in this study.

The specification of the broiler supply function is based on the economic theory, production pattern, and the information from previous works. In this study, a single equation supply model will be employed, although it is useful to estimate each stage of production for understanding the sequential structure of production and adjustment. It is important to understand the intermediate stage of production. However, the simpler the model specification is, the better the model is, providing that much of the common and important facts underlying the economic behavior can be explained by the simpler model. Here, the broiler supply functions are expressed in the following forms.

$$Q_t = f(BP_{t-n}, FP_{t-n}, CP_{t-n}, FCR_t, Q_{t-n}) \qquad (5.4)$$

$$Q_t = f(BFPR_{t-n}, RCP_{t-n}, FCR_t, Q_{t-n}) \qquad (5.5)$$

where Q_t is quantity of broilers produced in liveweight in t^{th} period,

BP_{t-n} is broiler price per pound in liveweight at farm level lagged n quarters,

FP_{t-n} is feed price paid by producers per ton lagged n quarters,

CP_{t-n} is chick price paid by producers per 100 lagged n quarters,

FCR_t is feed conversion ratio at t^{th} period,

$BFPR_{t-n}$ is broiler feed price ratio lagged n quarters,

RCP_{t-n} is chick's price in terms of feed price lagged n quarters, and

Q_{t-n} is dependent variable lagged n quarters.

The model with n = 1 assumes that there is a flexibility in the hatchery supply flock to adjust the proportion of eggs produced that are actually used for hatching purposes, according to the changing situation in the industry such as change in demand for chicks and change in broiler prices. It should be noted that the hatching rate of eggs for incubation for production of broiler-type chicks is about 80-85 percent of the eggs set for broiler-type chickens. The remaining portion is used for egg processing and fresh meat. Since there is a flexibility in the hatchery supply flock to adjust their level of egg utilization for hatching, it is reasonable to assume that broiler production decisions are made 1 quarter earlier. It can be justified that the broiler supply is a function of the broiler price, feed price and chick price lagged one quarter, and the feed conversion ratio, even though the whole stage of production process requires about 9 months.

The model with n = 3 assumes that there is a lack of flexibility enough to meet the changing economic conditions in the hatchery supply flock. Since it takes about 6 months to substantially increase the production level of eggs in the hatchery supply flock, broiler production would be a function of decisions made 3 quarters earlier. Therefore, the broiler supply would be a function of the broiler price, feed price, and chick price lagged 3 quarters and the feed conversion ratio. However, different combinations of n for each variable can be attempted to find a better model.

Quarterly data from 1959 to 1980 will be used to estimate the coefficients of the broiler supply structure. Calendar year quarters beginning with January are used. All prices employed in this study are expressed in real terms, by dividing their nominal values by the implicit GNP deflator, based on the assumption that broiler producers react to real price instead of nominal price. The implicit GNP deflator with 1972 as the base is used to deflate price.

VI. ESTIMATION I (BROILER PRICE)

The broiler supply function in Equation 5.4, with an application of the transformation of variables discussed in Chapter 4, will be estimated and interpreted in this section. The equation to be estimated is in the following form:

$$\frac{Q_t^{\lambda_o} - 1}{\lambda_o} = \beta_o + \beta_1 \frac{BP_{t-n}^{\lambda_1} - 1}{\lambda_1} + \beta_2 \frac{FP_{t-n}^{\lambda_2} - 1}{\lambda_2} + \beta_3 \frac{CP_{t-n}^{\lambda_3} - 1}{\lambda_3}$$
$$+ \beta_4 \frac{FCR_t^{\lambda_4} - 1}{\lambda_4} + \beta_5 \frac{Q_{t-n}^{\lambda_5} - 1}{\lambda_5} \qquad (6.1)$$

The names of variables used were defined in the previous chapter. The broiler supply function in Equation 6.1 is expressed in terms of real prices, rather than relative prices. All computations for estimation hereafter were performed using an econometric computer program, SHAZAM, version 4.0 [62].

A. Functional Form of Broiler Supply

The purpose of estimating a broiler supply function is (1) to find the price elasticity of supply of broilers, short run and long run, (2) to find the effect of technology on the supply elasticity and (3) to test the irreversible phenomena of broiler supply. The estimations were done using four different functional forms: (1) linear functional form, (2) linear-in-logarithms functional form, (3) a functional form with an application of Box-Cox transformation to each variable with the same transformation parameter (BC model), and (4) a functional form of Box-Cox transformation to each variable with different transformation parameters (GBC model).

It should be noted before the discussion of computational results that 10 out of the 12 GBC models presented in this chapter failed during the iterations with a floating-point overflow. The computations may be successful by dividing all variables by a constant (i.e., 100 or 1,000), but this attempt is not made here because marginal gains in terms of additional information are not likely to be high with respect to marginal costs. The blanks in the GBC models in Tables 6.1 through 6.12 except 6.2 and 6.4 mean failure of computations.

The estimation results are presented in Table 6.1 through 6.12 with (1) t-ratios of estimates, (2) elasticities evaluated at mean values over the sample period (except for the logarithmic model), and (3) the values of the transformation parameters for each variable, except for the linear and logarithmic models, directly below the estimated coefficients. The values of the log likelihood functions for each value of the transformation parameter, multiple coefficients of determinations (R^2), and Durbin-Watson/Durbin-h statistics are also presented.

The computational results demonstrate the following:

1) The longer the lag (larger n), the lower the significance level for broiler price becomes statistically.

2) The significance level for broiler price is generally higher with a lagged dependent variable than without it.

3) The estimates for the broiler-type baby chick's price have a positive sign in all models, even if they are expected to

Table 6.1. Broiler supply with broiler price, feed price, chick price, and dependent variable lagged one quarter with current feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	BP_{i-1}
	-537.480			-1835.4	16.288
Linear	t		Q_t	(-3.8097)	(1.7326)
	ε				(0.1240)
Logarithmic	-541.083		$\log Q_t$	0.3203	0.1530
	t			(0.4132)	(1.8779)
	-536.348			-169.05	3.3291
BC	t		$Q_t(\lambda)$	(-3.6410)	(1.8178)
	ε				(0.1331)
	λ	(0.66)			(0.66)
GBC			$Q_t(\lambda)$		

[a] L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b] H for Durbin-h statistics.

[c] df for degrees of freedom.

FP_{i-1}	CP_{i-1}	FCR	Q_{i-1}	R^2	H^b	df^c
-5.6237	32.751	72.164	0.4562	0.9623	2.8484	78
(-3.1234)	(1.7179)	(5.7570)	(4.8489)			
(-0.2803)	(0.1554)	(1.3064)	(0.4503)			
-0.3286	0.1014	1.6347	0.2771	0.9583	3.0399	78
(-3.2660)	(0.7600)	(6.6982)	(2.7094)			
-2.1373	5.0324	20.124	0.3914	0.9623	3.2561	
(-3.2478)	(1.4681)	(6.1524)	(3.9989)			78
(-0.2953)	(0.1472)	(1.4251)	(0.3880)			
(0.66)	(0.66)	(0.66)	(0.66)			

Table 6.2. Broiler supply with broiler price, feed price, and dependent variable lagged one quarter with current feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	BP_{i-1}
	-539.040			-1185.1	22.457
Linear		t	Q_t	(-3.9291)	(2.5534)
		ε			(0.1710)
Logarithmic	-541.392		$\log Q_t$	0.8092	0.1749
		t		(1.8766)	(2.3014)
	-537.444			-71.723	3.0800
BC		t	$Q_t(\lambda)$	(-3.9647)	(2.5137)
		ε			(0.1733)
		λ	(0.59)		(0.59)
	-533.180			-14.157	3.0534
GBC		t	$Q_t(\lambda)$	(-0.2232)	(2.1843)
		ε			(0.1365)
		λ	(0.81)		(1.0992)

[a]L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b]H for Durbin-h statistics.

[c]df for degrees of freedom.

FP_{i-1}	FCR_i	Q_{i-1}	R^2	H^b	df^c
-5.2696	60.951	0.4825	0.9609	3.0891	79
(-2.9103)	(5.6266)	(5.1340)			
(-0.2627)	(1.1035)	(0.4762)			
-0.3167	1.5508	0.2710	0.9579	3.0361	79
(-3.1952)	(7.1441)	(2.6652)			
-1.6532	13.814	0.3855	0.9612	3.7122	79
(-3.0889)	(6.2861)	(3.8927)			
(-0.2818)	(1.2954)	(0.3825)			
(0.59)	(0.59)	(0.59)			
-2.6732	13.017	0.000015	0.9654	1.0695	79
(-3.5107)	(11.066)	(5.0861)			
(-0.2971)	(1.4558)	(0.2885)			
(0.85843)	(1.0898)	(2.0789)			

Table 6.6. Broiler supply with broiler price, feed price, and dependent variable lagged two quarters with current feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	BP_{i-2}
	-552.021			-2165.3	8.2339
Linear		t	Q_t	(-6.1288)	(0.7976)
		ε			(0.0629)
Logarithmic	-530.123		$\log Q_t$	1.4645	-0.01896
		t		(3.8656)	(-0.2836)
				2.7307	-0.0124
BC	-529.324	t	$Q_t(\lambda)$	(12.739)	(-0.3855)
		ε			(-0.02573)
		λ	(-0.15)		(-0.15)
GBC			$Q_t(\lambda)$		

[a]L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b]H for Durbin-h statistics.

[c]df for degrees of freedom.

[d]N.A. for not available.

FP_{i-1}	CP_{i-1}	FCR_i	R^2	DW^b	df^c
-6.6734	47.770	126.41	0.9510	1.1211	79
(-3.2935)	(2.2402)	(19.726)			
(-0.3326)	(0.2266)	(2.2885)			
-0.3461	0.0731	2.1765	0.9543	1.5110	79
(-3.3173)	(0.5288)	(14.966)			
-0.9858	0.8865	9.3284	0.9558	1.3773	79
(-3.3699)	(1.0799)	(16.966)			
(-0.3349)	(0.1292)	(2.2009)			
(0.36)	(0.36)	(0.36)			
					79

Table 6.5. Broiler supply with broiler price, feed price, chick price, and dependent variable lagged two quarters with current feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	BP_{i-2}
				-3707.3	-6.5517
Linear	-544.909	t	Q_t	(-7.1093)	(-0.6354)
		ε			(-0.0501)
Logarithmic	-526.434		$\log Q_t$	0.0383	-0.0841
		t		(0.0594)	(-1.2222)
				1.8306	-0.0503
BC	-526.083	t	$Q_t(\lambda)$	(4.9373)	(-1.2456)
		ε			(-0.0859)
		λ (-0.11)			(-0.11)
GBC			$Q_t(\lambda)$		

[a] L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b] H for Durbin-h statistics.

[c] df for degrees of freedom.

FP_{i-1}	FCR_i	R^2	DW^b	df^c
-6.2334	114.29	0.9479	0.9974	80
(-3.0161)	(32.471)			
(-0.3107)	(2.0691)			
-0.3372	2.1070	0.9542	1.4996	80
(-3.2897)	(33.974)			
-0.7918	6.9323	0.9552	1.3683	80
(-3.2595)	(34.566)			
(-0.3220)	(2.0807)			
(0.30)	(0.30)			
-4.7957	0.0837	0.9604	1.4348	80
(-4.2837)	(38.413)			
(-0.3686)	(2.0374)			
(0.6840)	(2.3891)			

Table 6.3. Broiler supply with broiler price, feed price, and chick price lagged one quarter with current feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	BP_{i-1}
	-548.545			-3079.5	11.242
Linear		t	Q_t	(-6.6622)	(1.0614)
		ε			(0.0856)
Logarithmic	-544.860		$\log Q_t$	0.6444	0.1277
				(0.8095)	(1.5178)
	-542.823			-26.463	0.6459
BC			$Q_t(\lambda)$	(-3.9437)	(1.3931)
		ε			(0.1116)
		λ	(0.36)		(0.36)
GBC			$Q_t(\lambda)$		

[a] L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b] DW for Durbin-Watson statistics.

[c] df for degrees of freedom.

FP_{i-2}	CP_{i-2}	FCR	Q_{i-2}	R^2	H^b	df^c
-5.6653	78.086	143.02	-0.1045	0.9551	12.556	78
(-2.9004)	(3.7938)	(10.698)	(-1.0227)			
(-0.2831)	(0.3725)	(2.5892)	(-0.1019)			
-0.3280	0.2940	3.3549	-0.4986	0.9705	7.7437	78
(-3.9124)	(2.6760)	(16.676)	(-5.8257)			
-0.2425	0.1587	2.1968	-0.5216	0.9711	7.2626	
(-4.0151)	(2.5255)	(17.188)	(-6.2462)			78
(-0.3372)	(0.2857)	(3.4153)	(-0.5230)			
(-0.11)	(-0.11)	(-0.11)	(-0.11)			

Table 6.4. Broiler supply with broiler price and feed price lagged one quarter with current feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	BP_{i-1}
	-551.132			-2212.5	20.048
Linear		t	Q_t	(-8.5432)	(1.9891)
		ε			(0.1526)
Logarithmic	-545.009		$\log^{Q_t}$	0.9939	0.1440
		t		(2.2509)	(1.8478)
	-543.377			-12.151	0.6177
BC		t	$Q_t(\lambda)$	(-4.9584)	(1.9082)
		ε			(0.1430)
		λ (0.30)			(0.30)
	-538.600			313.94	0.0328
GBC		t	$Q_t(\lambda)$	(8.5381)	(1.7937)
		ε			(0.1017)
		λ (0.75)			(2.3920)

[a] L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b] DW for Durbin-Watson statistics.

[c] df for degrees of freedom.

FP_{i-2}	FCR_i	Q_{i-2}	R^2	H^b	df^c
-4.9649	117.39	-0.049656	0.9468	N.A.[d]	79
(-2.3609)	(9.4098)	(-0.4539)			
(-0.2481)	(2.1252)	(-0.0484)			
-0.2991	3.1243	-0.5205	0.9678	8.8194	79
(-3.4647)	(16.553)	(-5.8844)			
-0.1999	1.7641	-0.5517	0.9689	7.8897	79
(-3.6373)	(17.522)	(-6.4979)			
(-0.3134)	(3.2200)	(-0.5538)			
(-0.15)	(-0.15)	(-0.15)			

Table 6.7. Broiler supply with broiler price, feed price, and chick price lagged two quarters with feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	BP_{i-2}
	-545.469			-3431.2	-5.3074
Linear		t	Q_t	(-7.6883)	(-0.5182)
		ε			(-0.0405)
Logarithmic	-541.606		$\log Q_t$	-0.5695	-0.0367
		t		(-0.7506)	(-0.4512)
	-539.409			-34.926	-0.2234
BC		t	$Q_t(\lambda)$	(-5.4553)	(-0.4996)
		ε			(-0.0386)
		λ	(0.36)		(0.36)
GBC			$Q_t(\ )$		

[a] L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b] DW for Durbin-Watson statistics.

[c] df for degrees of freedom.

FP_{i-2}	CP_{i-2}	FCR_i	R^2	DW^b	df^c
-5.4824	75.107	130.86	0.9545	1.2190	79
(-2.8177)	(3.6851)	(21.364)			
(-0.2739)	(0.3583)	(2.3692)			
-0.3053	0.3552	2.3911	0.9577	1.6643	79
(-3.0619)	(2.7285)	(17.550)			
-0.8397	2.3623	9.9869	0.9592	1.5256	79
(-3.0061)	(3.0453)	(19.320)			
(-0.2855)	(0.3448)	(2.3563)			
(0.36)	(0.36)	(0.36)			

Table 6.8. Broiler supply with broiler price and feed price lagged two quarters with current feed conversion ratio

Model	L_{max}		Dependent	Intercept	BP_{i-2}
	-552.131			-2060.0	8.5637
Linear		t	Q_t	(-7.7714)	(0.8357)
		ε			(0.0654)
Logarithmic	-545.388		$\log Q_t$	1.1368	0.0453
		t		(2.5455)	(0.5762)
	-543.960			-9.0545	0.1816
BC		t	$Q_t(\lambda)$	(-4.1028)	(0.6107)
		ε			(0.0464)
		λ	(0.28)		(0.28)
GBC			$Q_t(\lambda)$		

[a] L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b] DW for Durbin-Watson statistics.

[c] df for degrees of freedom.

FP_{i-2}	FCR_i	R^2	DW[b]	df[c]
-4.8892	111.97	0.9466	1.1186	80
(-2.3439)	(31.049)			
(-0.2443)	(2.0271)			
-0.2688	2.0583	0.9537	1.6392	80
(-2.6170)	(32.611)			
-0.5879	6.2565	0.9546	1.5168	80
(-2.5555)	(33.111)			
(-0.2541)	(2.0347)			
(0.28)	(0.28)			

Table 6.9. Broiler supply with broiler price, feed price, chick price, and dependent variable lagged three quarters with current feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	BP_{i-3}
	-543.723		Q_t	-2385.4	4.6834
Linear		t		(-4.7245)	(0.4606)
		ε			(0.0360)
Logarithmic	-543.634		$\log Q_t$	-0.2604	-0.0313
		t		(-0.3346)	(-0.3686)
	-540.995			-61.901	0.0139
BC		t	$Q_t(\lambda)$	(-4.5181)	(0.0177)
		ε			(0.0014)
		λ	(0.47)		(0.47)
GBC			$Q_t(\lambda)$		

[a] L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b] H for Durbin-h statistics.

[c] df for degrees of freedom.

FP_{i-3}	CP_{i-3}	FCR_i	Q_{i-3}	R^2	H^b	df^c
-4.9271	50.530	90.702	0.3214	0.9563	6.9886	78
(-2.5789)	(2.5577)	(6.9877)	(3.1128)			
(-0.2471)	(0.2422)	(1.6421)	(0.3091)			
-0.2536	0.2676	2.1419	0.0753	0.9556	4.5731	78
(-2.4818)	(2.0685)	(8.8238)	(0.7113)			
-1.0057	3.1511	12.607	0.1783	0.9577	7.3745	78
(-2.5585)	(2.3555)	(8.0514)	(1.6833)			
(-0.2464)	(0.2561)	(1.9132)	(0.1750)			
(0.47)	(0.47)	(0.47)	(0.47)			

Table 6.10. Broiler supply with broiler price, feed price, and dependent variable lagged three quarters with current feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	BP_{i-3}
	-547.105		Q_t	-1407.3	14.362
Linear		t		(-4.1267)	(1.4710)
		ε			(0.1105)
Logarithmic	-545.877		$\log Q_t$	1.0547	0.0297
		t		(2.3044)	(0.3662)
	-543.828			-22.022	0.4388
BC		t	$Q_t(\lambda)$	(-3.9143)	(0.8140)
		ε			(0.0626)
		λ	(0.4)	(0.4)	(0.4)
GBC			$Q_t(\lambda)$		

[a] L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b] H for Durbin-h statistics.

[c] df for degrees of freedom.

FP_{i-3}	FCR_i	Q_{i-3}	R^2	H^b	df^c
-4.6277	75.691	0.3441	0.9526	11.003	79
(-2.3458)	(6.3198)	(3.2327)			
(-0.2321)	(1.3703)	(0.3308)			
-0.2346	1.9501	0.0483	0.9532	6.6130	79
(-2.2591)	(8.5182)	(0.4512)			
-0.7583	8.6399	0.1470	0.9547	24.853	79
(-2.3114)	(7.7016)	(1.3514)			
(-0.2290)	(1.7363)	(0.1447)			
(0.4)	(0.4)	(0.4)			

Table 6.11. Broiler supply with broiler price, feed price, and chick price lagged three quarters with feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	BP_{i-3}
	-548.640			-3174.9	2.3463
Linear		t	Q_t	(-6.9025)	(0.2196)
		ε			(0.0180)
Logarithmic	-543.906		$\log Q_t$	-0.1633	-0.0369
		t		(-0.2139)	(-0.4376)
	-542.172			-24.514	-0.0898
BC		t	$Q_t(\lambda)$	(-4.5398)	(-0.2229)
		ε			(-0.0180)
		λ (0.33)			(0.33)
GBC			$Q_t(\lambda)$		

[a] L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b] DW for Durbin-Watson statistics.

[c] df for degrees of freedom.

FP_{i-3}	CP_{i-3}	FCR_i	R^2	DW^b	df^c
-5.4172	55.798	126.69	0.9509	1.2770	79
(-2.7004)	(2.6906)	(20.367)			
(-0.2717)	(0.2675)	(2.2935)			
-0.2570	0.2563	2.2859	0.9553	1.7125	79
(-2.5265)	(2.0024)	(17.112)			
-0.6840	1.4423	8.4987	0.9565	1.5896	79
(-2.6064)	(2.1669)	(18.502)			
(-0.2548)	(0.2476)	(2.2616)			
(0.33)	(0.33)	(0.33)			

Table 6.12. Broiler supply with broiler price and feed price lagged three quarters with current feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	BP_{i-3}
	-552.323			-2148.6	12.930
Linear		t	Q_t	(-0.0507)	(1.2537)
		ε			(0.0994)
Logarithmic	-545.945		$\log Q_t$	1.0817	0.0244
		t		(2.3960)	(0.3054)
	-544.563			-9.3556	0.1644
BC		t	$Q_t(\lambda)$	(-4.1915)	(0.5443)
		ε			(0.0421)
		λ (0.28)			(0.28)
GBC			$Q_t(\lambda)$		

[a] L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b] DW for Durbin-Watson statistics.

[c] df for degrees of freedom.

FP_{i-3}	FCR_i	R^2	DW^b	df^c
-5.1224	112.80	0.9464	1.1822	80
(-2.4630)	(31.266)			
(-0.2569)	(2.0422)			
-0.2374	2.0493	0.9531	1.6641	80
(-2.3014)	(32.311)			
-0.5461	6.2508	0.9540	1.5531	80
(-2.3656)	(32.917)			
(-0.2362)	(2.0329)			
(0.28)	(0.28)			

have a negative sign, and their significance levels are generally high.

Fisher's words [14, p. 49] will be borrowed for (3) above:

> A scrutiny of the movement of baby chick prices relative to those for farm chickens since 1930 suggests that these prices move more or less in proportion. If this is so there would be a case, in theory, for treating them as a composite commodity. Since one enters the production function as a product and the other as a factor, they should have opposite influences in the supply function for chickens. If this close correspondence between the two sets of prices held throughout our sample period, it is probable that the coefficients of the price of chickens in both the egg and chicken supply equations are biassed downwards, if these are interpreted as relating to product price responses.

Therefore, it can be concluded from an economic and statistical sense that the model which seems to best explain the broiler supply is in the following form:

$$Q_t = f[BP_{t-1}, FP_{t-1}, FCR_t, Q_{t-1}] \qquad (6.2)$$

This demonstrates that there is enough flexibility in the hatchery supply flock to adjust the level of egg utilization for hatching for broiler producers according to the market situations in the broiler industry. The estimation results for Equation 6.2 are shown in Table 6.2. All the estimates of the coefficients in any model for Equation 6.2 have signs consistent with economic theory. Therefore, all discussions in this chapter are based on the information contained in Table 6.2.

Since all the models of linear, logarithmic and BC models are subfamilies of the GBC model, and since the same data are used in the estimation process, the values of the log likelihood functions for the different models will be used as a test criterion to find the best model. The estimation results indicate that the value of the log-likelihood function increases with increasing generality of the parametric family or less restrictions on the functional form. The value of the log likelihood functions is maximized at -533.180 in the GBC model. Under general conditions $2(L_{max} - \hat{L}_{max})$ is distributed as $\chi^2(k)$, where L_{max} is the maximum value of the log likelihood function without restrictions and $\hat{L}_{max}$ is the maximum value of the log likelihood function under k restrictions of parameters. The GBC model can be compared to all other models, because the GBC model corresponds to the unconstrained maximum. The linear and logarithmic models, in terms of the GBC model, have five restrictions, respectively: (1) $\lambda_o = 1$ or 0, (2) $\lambda_o = \lambda_1$, (3) $\lambda_o = \lambda_2$, (4) $\lambda_o = \lambda_3$ and (5) $\lambda_o = \lambda_4$. The BC model has four restrictions: (1) $\lambda_o = \lambda_1$, (2) $\lambda_o = \lambda_2$, (3) $\lambda_o = \lambda_3$ and (4) $\lambda_o = \lambda_4$.

Likelihood ratio tests are performed using the values of the log-likelihood functions. First, the null hypothesis that the functional form of the broiler supply is in either the linear (all λ_is equal to one) or logarithmic (all λ_is equal to zero) functional form is tested. The critical region for a large sample likelihood ratio test of the null hypothesis at the significance level α is

$$2[L_{max}(\hat{\lambda}_i) - L_{max}(\text{all } \lambda_i\text{s} = 1 \text{ or } 1)] > \chi^2_\alpha(5) \qquad (6.3)$$

where $\chi^2_\alpha(5)$ denotes the upper α significance point of a chi-square distribution with five degrees of freedom.

Second, the null hypothesis that all λ_is are equal in Equation 6.1 is tested. The critical region for a likelihood ratio test of the null hypothesis at the significance level α is

$$2[L_{max}(\hat{\lambda}_i) - L_{max}(\text{all } \lambda_i\text{s are equal})] > \chi^2_\alpha(4) \tag{6.4}$$

where $\chi^2_\alpha(4)$ denotes the upper α significance point of a chi-square distribution with four degrees of freedom.

Three tests are summarized in Table 6.13 with critical values of chi-square distribution at the 0.05 significance level and the test statistics.

Table 6.13. Likelihood ratio tests for functional form

Models compared	Value of test statistics	Critical value
GBC - linear	11.72	11.07 (5)
GBC - logarithmic	16.424	11.07 (5)
GBC - BC	8.528	9.49 (4)

Based on Table 6.13, the following conclusions are made. The null hypothesis that the functional form of the broiler supply is either linear or logarithmic is rejected at the 0.05 level. On the other hand, the null hypothesis that all the transformation parameters for each variable are equal cannot be rejected at the 0.05 level. This suggests that the broiler supply function is neither linear nor logarithmic.

According to the calculated Durbin-h statistics, the null hypothesis that there is no autocorrelation is rejected at both the $\alpha = 0.05$ and $\alpha = 0.01$ significance level when the broiler supply model is linear, a logarithmic, or even BC model. On the other hand, the null hypothesis is accepted under the GBC model. Since one of the causes of autocorrelated residuals in a time-series regression is an incorrect specification of the functional form of the relationship between variables, the results of the Durbin-h statistics demonstrate that the GBC model should be of a better specification than any of the other models (linear, logarithmic and BC models). With respect to R^2, all the models have a high degree of fit, which is higher than 0.95. The GBC model has the highest R^2 of 0.9654.

Based on the values of the log likelihood functions and on the tests of the functional form and autocorrelation, it is concluded that the GBC model best explains the structure of broiler supply. Therefore, an interpretation of the estimates of the GBC model will follow with comparisons to other models. The coefficients of all the variables in each model have signs consistent with economic theory. The estimates of feed price, feed conversion rates, and lagged dependent variables are highly significant at the 0.01 level in each model. The coefficient of the broiler price is significant at the 0.05 level in each model, but most significant in the linear model. The significance level of the intercept terms varies greatly among the models: highly significant at the 0.01 level in the linear and BC models, significant at the 0.1 level in the logarithmic model, but not statistically significant in the GBC model.

The short-run price elasticities of broilers, evaluated at the mean values, are 0.171, 0.175, 0.173 and 0.137 for the linear, logarithmic, BC and GBC models, respectively. If the GBC model is used as a discrimination tool, the elasticities are overestimated by 25 percent, 28 percent and 26 percent in the linear, logarithmic and BC models, respectively. This suggests that the future supply of broiler production will be overestimated if the estimated results from the three models are used for forecasting purposes.

The changing trends of the supply elasticities can be considered by providing the elasticity of broiler supply for selected years at an interval of five years, as shown in Table 6.14. Each elasticity is calculated at the mean values of quantity produced and price of each year. The elasticity trends downward in all models, except for the logarithmic model, satisfying the economic theory that producers of agricultural products become less responsive to price over time. As broiler price received by producers in real terms fell from 25.7 cents per pound in liveweight in the first quarter of 1960 to 16.6 cents in the last quarter of 1980, and as production increased from 1,099 million pounds in liveweight to 3,695 million pounds during the same period, the supply elasticity of broilers fell from 0.430 to 0.092 in the linear model, was constant at 0.175 in the logarithmic model, decreased from 0.298 to 0.120 in the BC model, and fell from 0.313 to 0.079 in the GBC model. The positive values of λ_is for quantity produced and broiler price in the linear, BC and GBC models imply that the supply elasticity is decreasing

Table 6.14. Supply elasticity of broiler for selected years in the U.S.

Model Year	Linear	Logarithmic	BC	GBC
1960	0.430	0.175	0.298	0.313
1965	0.254	0.175	0.219	0.193
1970	0.131	0.175	0.148	0.103
1975	0.169	0.175	0.172	0.139
1980	0.092	0.175	0.120	0.079

as broiler price in terms of quantity produced decreases, and in reality, broiler price has tended downward while broiler production has increased sharply.

The calculated long-run elasticities are 0.330, 0.240, 0.282 and 0.137 for the linear, logarithmic, BC and GBC models, respectively. Assuming that the GBC model is used as a discrimination tool, the long-run elasticities are overestimated by 141 percent, 75 percent and 106 percent for the linear, logarithmic and BC models, respectively. As economic theory implies, broiler producers are more sensitive to price in the long run than in the short run in the linear, logarithmic and BC models. On the other hand, both elasticities of the short run and long run are almost the same in the GBC model, but the long-run elasticity is slightly higher than the short-run elasticity. On the average, during the period of 1960-1980, a one-cent increase in real price of broilers in liveweight was associated with an increase of 18.0 million pounds of broilers in liveweight, based on the GBC model. According to the GBC model, a one

Table 6.15. Short-run and long-run elasticities of broiler supply in the U.S.: 1960-1980

Model \ Elasticities	Short-run	Long-run
Linear	0.171	0.330
Logarithmic	0.175	0.240
BC	0.173	0.282
GBC	0.13654 (≈ 0.137)	0.136542 (≈ 0.137)

percent increase in the broiler price in real terms increases broiler production by 0.137 percent both in the short run and in the long run. A one percent increase in the feed price decreases production by 0.297 percent, and a one percent increase in the feed conversion ratio increases production by 1.456 percent. Hence, it can be concluded that broiler producers have been more responsive to technological improvement than to broiler prices or feed prices over the sample period of 1960 to 1980.

Thus, the next step is to find an effect of technical progress on the producers' response to price. The effect of an improvement in the feed conversion ratio on the supply elasticity cannot be considered with the logarithmic model since the derivative of the supply elasticity with respect to the feed conversion ratio is zero because of a constant elasticity in this model. Effects of an increase in the feed conversion ratio on the short-run supply elasticity of broilers (i.e., $\frac{\partial \eta}{\partial FCR}$) are -0.004, -0.003 and -0.004 for the linear, BC and GBC models, respectively. In all three models, an improvement in the feed conversion ratio would result in a decrease in the short-run supply elasticity. The effect is the same in the linear and GBC models, while the BC model underestimates the effect by 33 percent over the GBC model. The effects on the long-run supply elasticity are -0.016, -0.008 and -0.004 for the linear, BC and GBC models, respectively. Thus, an improvement in the feed conversion ratio also reduces the long-run supply elasticity. The effects are overestimated by 100 percent and 300 percent, in the BC and linear models, respectively, as compared with the GBC model. These results demonstrate that broiler producers become less responsive to price with an increase in feed efficiency. These also indicate that with an increase in feed efficiency, the broiler supply function becomes steeper, while moving to the right. To conclude with the GBC model, a numerical one unit increase in the feed conversion ratio was associated with a decrease of 0.004 (or 0.4 percent) of the broiler supply elasticity over the period of 1960 to 1980.

Thus, an explanation has focused on the functional form of the broiler supply and its interpretations. Estimation results show that the GBC model is the best to explain the structure of broiler supply. Consequently, only the GBC model will be employed in the next section to make a structural evaluation of the broiler supply function.

B. Structural Evaluation

In order to find a possible change in the broiler supply, two analyses will be made here: one is for a possible change between periods and another for a possible change among quarters. An analysis is made by adding a dummy variable to allow a change in intercept and slope, instead of estimating two separate equations by dividing periods.

The equation to be estimated for this purpose is

$$Q_t(\lambda_o) = \beta_o + D + \beta_1 BP_{t-1}(\lambda_1) + \beta_1' [D \cdot BP_{t-1}(\lambda_1)]$$
$$+ \beta_2 FP_{t-1}(\lambda_2) + \beta_3 FCR_t(\lambda_3) + \beta_4 Q_{t-1}(\lambda_4) \qquad (6.5)$$

where $D = \begin{cases} 0 \text{ for 1960-1972, and} \\ 1 \text{ for 1973-1980.} \end{cases}$

The values of each transformation parameter in Table 6.2 are directly applied to Equation 6.5. The reason for segmenting the sample period into 1960-1972 and 1973-1980 is that there was a sharp increase in the broiler price and feed price in 1973. The estimation results are shown in Table 6.16 with t-ratios below the estimates. In model A, only a dummy variable for a possible change in the intercept is added to the basic Equation 6.2 of broiler supply. In model B, a dummy variable is added to allow a change in the slope. In model C, two dummy variables for a simultaneous change in both the intercept and slope are added. All three models have a high degree of fit with respect to R^2 which is higher than 0.96. The Durbin-h statistics indicate that there is no autocorrelation in any of the three models at the 0.05 significance level.

In model A, all variables have correct signs, and are significant at the 0.05 level, except for the feed price. The significance level of the feed price declined, but is still significant at the 0.1 level.

Table 6.16. Structural change of broiler supply between periods

Model	Dependent	Intercept	D	$BP_{i-1}(\lambda_1)$	$D \cdot BP_{i-1}(\lambda_1)$
A	$Q_t(\lambda_o)$	-133.85	-25.833	3.3386	
		(-0.96876)[c]	(-0.97507)	(2.3368)	
B	$Q_t(\lambda_o)$	-299.39		4.7740	-2.3678
		(-1.5828)		(2.7225)	(-1.5986)
C	$Q_t(\lambda_o)$	-312.84	18.737	5.1720	-3.2001
		(-1.6244)	(0.43887)	(2.6091)	(-1.3273)

[a]h for Durbin-h statistics.

[b]df for degrees of freedom.

[c]Values in parentheses are t-ratios.

$FP_{i-1}(\lambda_2)$	$FCR_i(\lambda_3)$	$Q_{i-1}(\lambda_4)$	R^2	h[a]	df[b]
-1.9398	14.268	0.000015373	0.9658	0.94782	78
(-1.8120)	(8.2011)	(5.1671)			
-1.3649	16.269	0.000013844	0.9665	1.1668	78
(-1.2265)	(6.9425)	(4.6207)			
-1.4370	16.506	0.000013224	0.9666	1.2942	77
(-1.2710)	(6.8307)	(3.9187)			

The coefficient estimate of dummy variable D is not significant, and its negative sign indicates that the intercept trends downward in the 1973-1980 period, compared to the 1960-1972 period. In model B, the significance level of the broiler price increased, while that of the feed price declined. In this model, the estimate of $D \cdot BP_{t-1}(\lambda_1)$ is not significant at the 0.05 level, or even at the 0.10 level. However, the negative sign demonstrates that the broiler supply function becomes steeper in the 1973-80 period, compared with the 1960-72 period. In model C, the estimates of coefficients of D and $D \cdot BP_{t-1}(\lambda_1)$ are not significant even at the 0.10 level. The estimation results demonstrate that there is no statistically significant change in either the intercept or slope of the broiler supply function between two segmented periods, even if there was a sharp increase in the broiler and feed price in 1973. But the negative signs of the coefficient estimates of $D \cdot BP_{t-1}(\lambda_1)$ in models B and C imply that broiler producers become a little less responsive to price over time.

As shown in the analysis for a possible shift in the broiler supply function between periods, a single equation approach is employed again to find a possible structural difference among quarters by using a dummy variable for each quarter, instead of estimating four separate supply functions for each quarter.

The equation to be used for this purpose is:

$$Q_t(\lambda_o) = \beta_o + D_2 + D_3 + D_4 + \beta_1 \cdot BP_{t-1}(\lambda_1) + \beta_1' [D2 \cdot BP_{t-1}(\lambda_1)]$$
$$+ \beta_1'' [D_3 \cdot BP_{t-1}(\lambda_1)] + \beta_1''' [D_4 \cdot BP_{t-1}(\lambda_1)] + \beta_2 FP_{t-1}(\lambda_2)$$
$$+ \beta_3 FCR_t(\lambda_3) + \beta_4 Q_{t-1}(\lambda_4) \qquad (6.6)$$

where $D_2 = \begin{cases} 1 & \text{for second quarter,} \\ 0 & \text{otherwise} \end{cases}$

$D_3 = \begin{cases} 1 & \text{for third quarter,} \\ 0 & \text{otherwise} \end{cases}$

$D_4 = \begin{cases} 1 & \text{for fourth quarter,} \\ 0 & \text{otherwise} \end{cases}$

The values of the transformation parameters of λ_o, λ_1, λ_2, λ_3 and λ_4 come from Table 6.2. The estimation results for models D, E and F are shown in Table 6.17 with the t-ratios placed directly below the estimates. All three models have a high degree of fit with respect to R^2 which are higher than 0.98. According to the calculated Durbin-h statistics, the null hypothesis that there is no autocorrelation is rejected at the 0.05 level for all three models. Thus, an autoregressive model is estimated again after transforming the data with proper value of transformation parameter for each variable. This is a kind of General Box-Cox Auto-regressive model (GBC-AM), even if each λ_is and ρ, the autoregressive coefficient, are not estimated simultaneously. The estimation results for models G, H and I are presented in Table 6.17. One kind of dummy variable to indicate a possible change in either the intercept or slope

Table 6.17. Quarterly structure of broiler supply function: 1960-1980

Model	Dependent	Constant	D2	D3	D4
D	$Q_t(\lambda_o)$	4.7071	53.156	30.813	-16.813
		(0.1266)[a]	(9.0372)	(4.9902)	(-2.7187)
E	$Q_t(\lambda_o)$	-0.8632			
		(-0.0229)			
F	$Q_t(\lambda_o)$	76.629	19.284	-50.471	-92.538
		(1.8190)	(0.6782)	(-1.7021)	(-3.3281)
G (auto)	$Q_t(\lambda_o)$	-355.47	51.509	46.555	-4.3579
		(-4.0822)	(13.324)	(7.5508)	(-0.7504)
H (auto)	$Q_t(\lambda_o)$	-357.99			
		(-4.2135)			
I (auto0	$Q_t(\lambda_o)$	-28.528	20.242	-43.738	-71.539
		(-0.5001)	(1.0176)	(-1.7899)	(-3.4680)

[a]Values in parentheses are t-ratios.

$BP_{t-1}(\lambda_1)$	$D2 \cdot BP_{t-1}(\lambda_1)$	$D3 \cdot BP_{t-1}(\lambda_1)$	$D4 \cdot BP_{t-1}(\lambda_1)$
1.7408			
(2.1012)			
1.0202	2.4366	1.5871	-0.4980
(1.0660)	(8.5082)	(5.2887)	(-1.6579)
-0.9572	1.7849	3.8846	3.6075
(-0.7845)	(1.3526)	(2.8229)	(2.7977)
2.6428			
(2.9927)			
1.7231	2.3422	2.2475	-0.0148
(1.7021)	(12.644)	(8.2626)	(-0.0572)
0.5433	1.5925	3.6492	2.6718
(0.4853)	(1.7194)	(3.2920)	(2.8300)

Table 6.17. continued

$FP_{t-1}(\lambda_2)$	$FCR_t(\lambda_3)$	$Q_{t-1}(\lambda_4)$	R_2	h^b	ρ^c	df^d
-2.0207	11.755	0.000018	0.9898	2.7259		76
(-4.6519)	(16.754)	(9.9194)				
-2.0261	12.190	0.000017	0.9889	2.8186		76
(-4.4562)	(17.022)	(9.2272)				
-1.8941	11.160	0.000019	0.9911	2.8230		73
(-4.5441)	(15.935)	(10.818)				
-1.2270	18.419	0.0000017	0.9914		0.8089	
(-1.7525)	(11.561)	(0.4410)			(12.6085)	
-1.0601	18.637	0.0000011	0.9909		0.8126	
(-1.4705)	(12.322)	(0.3244)			(12.7766)	
-1.9620	12.968	0.000015	0.9922		0.4808	
(-3.7809)	(12.874)	(5.8647)			(5.0256)	

[b] h for Durbin-h statistics.

[c] ρ for autoregressive coefficients.

[d] df for degrees of freedom.

for each quarter is employed in models G and H. In model I, two kinds of dummy variables are employed to allow a simultaneous change in both the intercept and slope. All models have a high degree of fit. The values of the autoregressive coefficients are 0.8089, 0.8126 and 0.4808 for models G, H and I, respectively. They are significantly different from zero at the 0.05 level in any of the models. The tangible difference between the GBC and the GBC-AM models in Table 6.17 is that the significance level of the lagged dependent variable decreases sharply.

In model G, the coefficient estimates for D2 and D3 are highly significant at the 0.01 level, but are not statistically significant for D4. Additional tests are made for equality of intercepts between the second and third quarters (i.e., D2 = D3), between the second and fourth quarter (D2 = D4) and between the third and fourth quarter (D3 = D4). The results are shown in Table 6.18.

The tests rejected the null hypothesis of D2 = D4, and D3 = D4 at the 0.05 level, but did not reject D2 = D3 at the same level. This implies, based on model G, that the intercept of the broiler supply function is not statistically different between the first and fourth quarters, and between the second and third quarters. In model H, the coefficient estimates for $D2 \cdot BP_{t-1}(\lambda_1)$ and $D3 \cdot BP_{t-1}(\lambda_1)$ (which are dummy variables for a possible change in the slope for the second and third quarters, respectively, from the first quarter) are highly significant at the 0.01 level. However, $D4 \cdot BP_{t-1}(\lambda_1)$ is not significant. Addi-

Table 6.18. Equality tests of intercepts and slopes among quarters

			F^a	t^b	df	df
For model G	Test	D2 = D3	0.762	0.873	1	76
		D2 = D4	107.389	10.363	1	76
		D3 = D4	230.113	15.169	1	76
For model H	Test	$D2 \cdot BP_{t-1}(\lambda_1) = D3 \cdot BP_{t-1}(\lambda_1)$	0.196	0.433	1	76
		$D2 \cdot BP_{t-1}(\lambda_1) = D4 \cdot BP_{t-1}(\lambda_1)$	109.560	10.467	1	76
		$D3 \cdot BP_{t-1}(\lambda_1) = D4 \cdot BP_{t-1}(\lambda_1)$	215.776	14.689	1	76
For model I	Test	$\begin{cases} D2 = D3 \\ D2 \cdot BP_{t-1}(\lambda_1) = D3 \cdot BP_{t-1}(\lambda_1) \end{cases}$	9.559		2	73
	Test	$\begin{cases} D2 = D4 \\ D2 \cdot BP_{t-1}(\lambda_1) = D4 \cdot BP_{t-1}(\lambda_1) \end{cases}$	94.382		2	73
	Test	$\begin{cases} D3 = D4 \\ D3 \cdot BP_{t-1}(\lambda_1) = D4 \cdot BP_{t-1}(\lambda_1) \end{cases}$	88.049		2	73

[a] F for calculated F statistics.

[b] t for calculated t statistics.

tional tests are made for equality of the slopes between the second and third quarters [$D2 \cdot BP_{t-1}(\lambda_1) = D3 \cdot BP_{t-1}(\lambda_1)$], between the second and fourth quarters [$D2 \cdot BP_{t-1}(\lambda_1) = D4 \cdot BP_{t-1}(\lambda_1)$], and between the third and fourth quarters [$D3 \cdot BP_{t-1}(\lambda_1) = D4 \cdot BP_{t-1}(\lambda_1)$]. The results are presented in Table 6.18. Table 6.18 demonstrates that the slopes of the broiler supply function are not statistically different between the second and third quarters, but are different between the second and fourth quarters, and also between the third and fourth quarters. The models G and H imply that the structure of the broiler supply is not statistically different between the first and fourth quarters and between the second the third quarters. However, the result of model I contradicts the results of the models G and H. That is, the estimated coefficients of D4 and $D4 \cdot BP_{t-1}(\lambda_1)$ are highly significant in model I, implying that the slope and the intercept are simultaneously different between the first and fourth quarters. The estimates of D3 and $D3 \cdot BP_{t-1}(\lambda_1)$ are also significant at the 0.1 and 0.01 level, respectively, also implying that the supply structure between the first and third quarters are statistically different. The equality tests of both in the intercept and slope between quarters in Table 6.18 shows that the structure of broiler supply function is different between quarters.

C. Irreversibility of Broiler Supply

The broiler supply model with an assumption that the supply function is reversible has been estimated. In this section, an emphasis will be placed on the question of the irreversibility of the broiler supply function: "the broiler producers are less responsive to a price decrease than to a price increase as fixed asset theory implies." Only the GBC model will be employed again here in order to find a possible difference in supply structure between increasing-price and decreasing-price phases. The GBC model is selected since it provides a better specification for the broiler supply function. Two approaches will be used in order to test for possible differences in broiler producers' responses between rising prices and falling prices. The first approach is the use of a dummy variable to allow for a change in the slope of the supply curve with increasing and decreasing prices. The second approach is an application of the Wolffram's technique to split the broiler price into one variable for increasing prices and another for decreasing prices.[1] The transformation of data into the GBC model is made before the variable is segmented. The equation used for the first approach is:

$$Q_t(\lambda_o) = \beta_o + \beta_1 BP_{t-1}(\lambda_1) + \beta_1' [D \cdot BP_{t-1}(\lambda_1)] + \beta_2 FP_{t-1}(\lambda_2)$$

$$+ \beta_3 FCR_t(\lambda_3) + \beta_4 Q_{t-1}(\lambda_4) \qquad (6.7)$$

where $D = \begin{cases} 1 \text{ for price increasing phase, and} \\ 0 \text{ for price decreasing phase.} \end{cases}$

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[1]The methods by Houck (24), and Traill et al. (52) are not used here, since Houck's method is fundamentally the same as Wolffram's technique, and since Traill et al.'s method seems to not be so applicable here because of only 2 historical high prices over 84 observations.

The values of the transformation parameters for each variable come from Table 6.2. The estimated result is

$$\begin{aligned} Q_t(\lambda_o) = {} & \underset{(0.4317)}{28.437} + \underset{(1.1064)}{1.6961}\, BP_{t-1}(\lambda_1) + \underset{(1.988)}{0.70608}[D \cdot BP_{t-1}(\lambda_1)] \\ & - \underset{(-3.1510)}{2.3963}\, FP_{t-1}(\lambda_2) + \underset{(9.7863)}{12.127}\, FCR_t(\lambda_3) + \underset{(5.5307)}{0.000017}\, Q_{t-1}(\lambda_4) \end{aligned} \tag{6.8}$$

$$R^2 = 0.9670,\ \text{Durbin-h} = 1.2796,\ df = 78$$

The values in parentheses are t-ratios. The null hypothesis of no autocorrelation is accepted at the 0.05 level, based on the Durbin-h statistics. All of the estimates of coefficients have the right signs. The addition of $D \cdot BP_{t-1}(\lambda_1)$ sharply reduces the significance level of the broiler price, $BP_{t-1}(\lambda_1)$. The estimated coefficient of $D \cdot BP_{t-1}(\lambda_1)$ is statistically different from zero at the 0.05 level, implying that in producers' response to the broiler price there is a difference between the price-increasing phase and the price-decreasing phase. The positive sign of the estimate of $D \cdot BP_{t-1}(\lambda_1)$ indicates that broiler producers are more responsive to price in the price-increasing phase than in the price-decreasing phase. Therefore, statistical estimation by splitting the broiler price into two different phases is presented. The model with an assumed irreversible relationship between quantity produced of broilers and broiler price is,

$$Q_t(\lambda_o) = \beta_o + \beta_1 BPI_{t-1}(\lambda_1) + \beta_1' BPD_{t-1}(\lambda_1) + \beta_2 FP_{t-1}(\lambda_2)$$

$$+ \beta_3 FCR_t(\lambda_3) + \beta_4 Q_{t-1}(\lambda_4) \qquad (6.9)$$

The variable of the broiler price is segmented, according to the Wollfram's technique, into price-increasing phase, BPI, and price-decreasing phase, BPD, in order to test the irreversible nature of the broiler supply function.

The estimated result is,

$$Q_t(\lambda_o) = \underset{(0.8432)}{130.81} + \underset{(2.0919)}{3.3666}\ BPI_{t-1}(\lambda_1) - \underset{(-1.8767)}{2.8039}\ BPD_{t-1}(\lambda_1)$$

$$- \underset{(-3.1240)}{2.8890}\ FP_{t-1}(\lambda_2) + \underset{(3.2348)}{11.546}\ FCR_t(\lambda_3) + \underset{(4.4435)}{0.000014}\ Q_{t-1}(\lambda_4)$$

$$R^2 = 0.9654,\ \text{Durbin-h} = 0.9632,\ df = 78$$

The values in parentheses are t-ratios. Based on the Durbin-h statistic, the null hypothesis that there is no autocorrelation is accepted at the 0.05 level. The degree of fit is still high, which is 0.9654. All of the estimates of coefficients, except BPD, are very significant at the 0.05 level, while the estimate of the coefficient for BPD is significant at the 0.1 level. The estimated coefficient of BPI is greater than that of BPD in absolute values, implying that broiler producers are more responsive to rising prices than to falling prices. The calculated price elasticity of broiler supply with respect to rising prices is 0.34544, while the elasticity with respect to falling prices is 0.31356. This result supports the irreversibility of the broiler supply function. However, the test of equality of $BPI(\lambda_1) = BPD(\lambda_1)$ in absolute terms is accepted at the 0.05 level. In other words, the null hypothesis that the broiler supply function is not irreversible is not rejected at the 0.05 level. Even though broiler producers are more responsive to rising prices than to falling prices, supporting the irreversible nature of broiler supply, their responsiveness is not statistically significant in differing from each other.

VII. ESTIMATION II (BROILER FEED PRICE RATIO)

In Chapter 6, the broiler supply function was explained by the real price. In this chapter the supply function will be explained by the relative price, the broiler feed price ratio. The same technique and procedure as employed in Chapter 6 will be used here again.

The equation to be estimated is:

$$\frac{Q_t^{\lambda_o} - 1}{\lambda_o} = \beta_o + \beta_1 \frac{BFPR_{t-n}^{\lambda_1} - 1}{\lambda_1} + \beta_2 \frac{RPC_{t-n}^{\lambda_2} - 1}{\lambda_2} + \beta_3 \frac{FCR_t^{\lambda_3} - 1}{\lambda_3} + \beta_4 \frac{Q_{t-n}^{\lambda_4} - 1}{\lambda_4} \qquad (7.1)$$

or

$$Q_t(\lambda_o) = \beta_o + \beta_1 \cdot BFPR_{t-n}(\lambda_1) + \beta_2 \cdot RPC_{t-n}(\lambda_2) + \beta_3 \cdot FCR_t(\lambda_3) + \beta_4 \cdot Q_{t-n}(\lambda_4) \qquad (7.2)$$

where Q_t is quantity produced of broiler in liveweight,

$BFPR_{t-n}$ is broiler feed price ratio lagged n quarters,

RPC_{t-n} is chick's price relative to feed price lagged n quarters,

FCR_t is feed conversion ratio,

Q_{t-n} is dependent variable lagged n-quarter,

λ_i is tranformation parameter; $i = 1, 2, 3, 4$

$t = 1, 2, \ldots, 84$, and

$n = 1, 2, 3.$

A. Functional Form of Broiler Supply

Equation 7.1 or 7.2 will be estimated using four different functional forms of the linear, logarithmic, BC and GBC form with the same data and comparisons will be made. It should be mentioned before the discussion of estimation results that 8 out of the 12 GBC models presented in this chapter failed during the iterations with a floating-point overflow. The computations may be successful by dividing all variables by a constant, but this attempt is not made here because of the same reasons as noted in Chapter 6.

The estimation results are presented in Tables 7.1 through 7.12 with (1) t-ratios of estimates, (2) elasticities evaluated at mean values over sample period, except the logarithmic model, and (3) the values of the transformation parameters for each variable, except for the linear and logarithmic models, directly below the estimated coefficients. The values of the log likelihood functions for each value of transformation parameter, multiple coefficient of determinations, Durbin-Watson/Durbin-h statistics are also presented.

Based on the computation results, the following conclusions are made:

1) The significance level of the broiler feed price ratio is higher with $n = 1$ than any other value of n.

2) The significance level of the broiler feed price ratio is generally higher with a lagged dependent variable than without it.

3) The estimates for the chick's price relative to the feed price have a positive sign in all models even if they are

Table 7.1. Broiler supply with broiler feed price ratio, relative chick price, and dependent variable lagged one quarter with current feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	$BFPR_{i-1}$
	-539.074			-2422.1	72.889
Linear		t	Q_t	(-5.0353)	(1.2569)
		ε			(0.0911)
Logarithmic	-541.784		$\log Q_t$	-1.0617	0.1166
		t		(-2.7471)	(1.5026)
	-537.585			-151.70	5.8843
BC		t	$Q_t(\lambda)$	(-5.7862)	(1.3781)
		ε			(0.0997)
		λ (0.61)			(0.61)
	-532.999			-753570	8361100
GBC		t	$Q_t(\lambda)$	(-1.9723)	(1.9702)
		ε			(0.0452)
		λ (0.86)			(-11.106)

[a] L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b] H for Durbin-h statistics.

[c] df for degrees of freedom.

RPC_{i-1}	FCR_i	Q_{i-1}	R^2	H^b	df^c
218.87	70.282	0.4680	0.9609	2.7925	79
(2.1806)	(5.7856)	(4.9712)			
(0.1720)	(1.2724)	(0.4619)			
0.1782	1.6887	0.2839	0.9575	2.3939	79
(2.1516)	(7.1443)	(2.8603)			
13.643	16.700	0.3845	0.9611	3.1040	79
(2.2150)	(6.3803)	(3.9317)			
(0.1742)	(1.4453)	(0.3815)			
(0.61)	(0.61)	(0.61)			
683.45	42.574	0.000002	0.9657	1.0758	79
(2.4471)	(12.033)	(5.4784)			
(0.1260)	(1.6157)	(0.2735)			
(-2.9321)	(0.90719)	(2.3814)			

Table 7.2. Broiler supply with broiler feed price ratio and dependent variable lagged one quarter with current feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	$BFPR_{i-1}$
	-541.529			-1677.8	111.82
Linear		t	Q_t	(-4.8382)	(1.9807)
		ε			(0.1398)
Logarithmic	-544.176		$\log Q_t$	-0.4536	0.1627
		t		(-1.6829)	(2.1329)
	-540.116			-114.87	8.6741
BC		t	$Q_t(\lambda)$	(-5.5337)	(2.0760)
					(0.1470)
		(0.61)			(0.61)
	-535.715			-83963.0	729870
GBC		t	$Q_t(\lambda)$	(-2.4589)	(2.4195)
		ε			(0.0781)
		λ (0.80)			(-8.8378)

[a] L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b] H for Durbin-h statistics.

[c] df for degrees of freedom.

FCR_i	Q_{i-1}	R^2	H^b	df^c
57.851	0.5104	0.9585	3.0469	80
(5.2708)	(5.4158)			
(1.0473)	(0.5038)			
1.4737	0.3183	0.9551	3.0753	80
(6.7294)	(3.1779)			
14.140	0.4242	0.9587	3.6055	80
(5.8792)	(4.3078)			
(1.2237)	(0.4208)			
(0.61)	(0.61)			
362.57	0.00000090	0.9632	1.1488	80
(13.047)	7.1618			
(1.3768)	(0.3241)			
(0.17512)	(2.4459)			

Table 7.3. Broiler supply with broiler feed price ratio and relative chick price lagged one quarter with current feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	$BFPR_{i-1}$
	-550.506			-3856.7	38.460
Linear		t	Q_t	(-8.8016)	(0.5867)
		ε			(0.0481)
Logarithmic	-545.923		$\log Q_t$	-1.2268	0.0830
		t		(-3.0752)	(1.0364)
	-543.923			-33.097	0.6869
BC		t	$Q_t(\lambda)$	(-9.8144)	(0.9133)
		ε			(0.0708)
		λ	(0.34)		(0.34)
	-539.482			-29605000.0	496270000.0
GBC		t	$Q_t(\lambda)$	(-1.5626)	(1.5626)
		ε			(0.0128)
		λ	(0.74)		(-16.763)

[a] L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b] DW for Durbin-Watson statistics.

[c] df for degrees of freedom.

RCP_{i-1}	FCR_i	R^2	DW^b	df^c
321.99	126.33	0.9486	1.1063	80
(2.8796)	(24.527)			
(0.2530)	(2.2870)			
0.2163	2.3177	0.9532	1.5137	80
(2.5354)	(25.617)			
2.5127	8.9378	0.9546	1.3982	80
(2.6523)	(25.885)			
(0.2211)	(2.2849)			
(0.34)	(0.34)			
519.17	0.4788	0.9596	1.3842	80
(3.6627)	(32.206)			
(0.1826)	(2.2699)			
(-3.3802)	(1.9360)			

Table 7.4. Broiler supply with broiler feed price ratio lagged one quarter and current feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	$BFPR_{i-1}$
	-554.548			-2912.6	93.488
Linear		t	Q_t	(-9.5957)	(1.4280)
		ε			(0.1169)
Logarithmic	-549.169		$\log Q_t$	-0.4938	0.1354
		t		(-1.7390)	(1.6932)
	-547.454			-22.944	1.0732
BC		t	$Q_t(\lambda)$	(-10.748)	(1.6322)
		ε			(1.1264)
		λ	(0.32)		(0.32)
	-545.310			-40688.0	397470.0
GBC		t	$Q_t(\lambda)$	(-2.1103)	(2.1123)
		ε			(0.0672)
		λ	(0.61)		(-9.76)

[a] L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b] DW for Durbin-Watson statistics.

[c] df for degrees of freedom.

FCR_i	R^2	DW^b	df^c
115.03	0.9433	0.9511	81
(33.011)			
(2.0825)			
2.1444	0.9494	1.3736	81
(35.033)			
7.6121	0.9506	1.2583	81
(35.475)			
(2.1086)			
(0.32)			
0.4928	0.9532	1.2030	81
(37.443)			
(2.1156)			
(1.6419)			

Table 7.5. Broiler supply with broiler feed price ratio, relative chick price, and dependent variable lagged two quarters with current feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	$BFPR_{i-2}$
	-546.512			-4143.9	-67.903
Linear		t	Q_t	(-8.1640)	(-1.0616)
		ε			(-0.0849)
Logarithmic	-527.259		$\log Q_t$	-1.6317	-0.1010
		t		(-5.1689)	(-1.5313)
	-527.131			-0.0777	-0.0676
BC		t	$Q_t(\lambda)$	(-0.3553)	(-1.5298)
		ε			
		λ	(-0.06)		(-0.06)
GBC			$Q_t(\lambda)$		

[a] L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b] H for Durbin-h statistics.

[c] df for degrees of freedom.

RPC_{i-1}	FCR_i	Q_{i-2}	R^2	H^b	df^c
468.66	138.29	-0.0838	0.9533	13.559	79
(4.3810)	(10.702)	(-0.8174)			
(0.3694)	(2.5036)	(-0.0817)			
0.3998	3.4104	-0.4705	0.9700	7.1740	79
(5.8739)	(17.433)	(-5.6611)			
0.2623	2.7115	-0.4815	0.9702	6.9184	79
(5.9311)	(17.765)	(-5.8728)			
(-0.06)	(-0.06)	(-0.06)			

Table 7.6. Broiler supply with broiler feed price ratio and dependent variable lagged two quarters with current feed conversion ratio

Model	L_{max} [a]		Dependent	Intercept	$BFPR_{i-2}$
	-555.647			-2610.1	19.742
Linear		t	Q_t	(-6.4106)	(0.2933)
		ε			(0.0247)
Logarithmic	-542.479		$\log Q_t$	-0.3245	0.0091
		t		(-1.2168)	(0.1210)
	-542.475			-0.5633	0.0097
BC		t	$Q_t(\lambda)$	(-1.9786)	(0.1200)
		ε			(0.0090)
		λ (0.01)			(0.01)
GBC			$Q_t(\lambda)$		

[a] L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b] H for Durbin-h statistics.

[c] df for degrees of freedom.

[d] N.A. for not available (cannot be computed).

FCR_i	Q_{i-2}	R^2	H^b	df^c
113.29	-0.0009	0.9420	N.A.[d]	80
(8.8199)	(-0.0078)			
(2.0510)	(-0.0009)			
2.9564	-0.4008	0.9568	11.902	80
(13.811)	(-4.0903)			
3.0706	-0.3987	0.9568	12.003	80
(13.768)	(-4.0613)			
(2.9499)	(-0.3986)			
(0.01)	(0.01)			

Table 7.7. Broiler supply with broiler feed price ratio and relative chick price lagged two quarters with current feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	$BFPR_{i-2}$
	-546.866			-3901.7	-60.822
Linear		t	Q_t	(-9.4865)	(-0.9617)
		ε			(-0.0761)
Logarithmic	-541.560		$\log Q_t$	-1.3978	-0.0416
		t		(-3.7910)	(-0.5418)
	-539.555			-31.692	-0.4889
BC		t	$Q_t(\lambda)$	(-10.830)	(-0.7257)
		ε			(-0.0539)
		λ	(0.33)		(0.33)
GBC			$Q_t(\lambda)$		

[a] L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b] DW for Durbin-Watston statistics.

[c] df for degrees of freedom.

RCP_{i-2}	FCR_i	R^2	DW^b	df^c
452.52	128.48	0.9529	1.1325	80
(4.3130)	(26.828)			
(0.3569)	(2.3260)			
0.3448	2.3777	0.9578	1.6635	80
(4.3448)	(28.563)			
3.6187	8.7924	0.9591	1.5173	80
(4.4118)	(28.803)			
(0.3423)	(2.3398)			
(0.33)	(0.33)			

Table 7.8. Broiler supply with broiler feed price ratio lagged two quarters and current feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	$BFPR_{i-2}$
	-555.647			-2608.0	19.786
Linear		t	Q_t	(-8.4001)	(0.2968)
		ε			(0.0247)
Logarithmic	-550.454		$\log Q_t$	-0.2776	0.0476
		t		(-0.9535)	(0.5830)
	-548.701			-21.705	0.31209
BC		t	$Q_t(\lambda)$	(-9.6264)	(0.4648)
		ε			(0.0368)
		λ (0.32)			(0.32)
GBC			$Q_t(\lambda)$		

[a] L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b] DW for Durbin-Watson statistics.

[c] df for degrees of freedom.

FCR_i	R^2	DW^b	df^c
113.19	0.9420	1.0244	81
(31.865)			
(2.0492)			
2.1128	0.9478	1.4799	81
(33.750)			
7.4950	0.9491	1.3593	81
(34.167)			
(2.0762)			
(0.32)			

Table 7.9. Broiler supply with broiler feed price ratio, relative chick price, and dependent variable lagged three quarters with current feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	$BFPR_{i-3}$
	-544.813			-2827.2	25.912
Linear		t	Q_t	(-5.8920)	(0.4127)
		ε			(0.0325)
Logarithmic	-543.700		$\log Q_t$	-1.1355	-0.0212
		t		(-3.0883)	(-0.2628)
	-541.349			-49.935	0.0207
BC		t	$Q_t(\lambda)$	(-7.1264)	(0.0162)
		ε			(0.0013)
		λ	(0.42)		(0.42)
GBC			$Q_t(\lambda)$		

[a]L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b]H for Durbin-h statistics.

[c]df for degrees of freedom.

RPC_{i-3}	FCR_i	Q_{i-3}	R^2	H^b	df^c
291.77	87.108	0.3373	0.9552	7.6031	79
(2.9053)	(6.9562)	(3.2692)			
(0.2304)	(1.5770)	(0.3243)			
0.2790	2.1457	0.0820	0.9556	3.0048	79
(3.5068)	(9.1079)	(0.8068)			
5.1334	10.367	0.1696	0.9573	5.7435	79
(3.2993)	(8.3029)	(1.6343)			
(0.2555)	(1.9227)	(0.1668)			
(0.42)	(0.42)	(0.42)			

Table 7.10. Broiler supply with broiler feed price ratio and dependent variable lagged three quarters with current feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	$BFPR_{i-3}$
	-549.077			-1926.2	82.457
Linear		t	Q_t	(-5.0319)	(1.3211)
		ε			(0.1034)
Logarithmic	-549.776		$\log Q_t$	-0.2607	0.0596
		t		(-0.9035)	(0.7224)
	-546.698			-63.765	2.2625
BC		t	$Q_t(\lambda)$	(-6.0010)	(1.0276)
		ε			(0.0801)
		λ	(0.50)		(0.50)
GBC			$Q_t(\lambda)$		

[a] L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b] H for Durbin-h statistics.

[c] df for degrees of freedom.

[d] N.A. for not available (cannot be computed).

FCR_i	Q_{i-3}	R^2	H^b	df^c
73.349	0.3764	0.9504	13.515	80
(6.0522)	(3.5190)			
(1.3279)	(0.3619)			
1.8555	0.1221	0.9486	11.717	80
(7.8745)	(1.1312)			
11.969	0.2292	0.9515	N.A.[d]	80
(7.0425)	(2.0976)			
(1.6104)	(0.2248)			
(0.50)	(0.50)			

Table 7.11. Broiler supply with broiler feed price ratio and relative chick price lagged three quarters with current feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	$BFPR_{i-3}$
	-550.143			-3742.2	6.6963
Linear		t	Q_t	(-9.0683)	(0.1012)
		ε			(0.0084)
Logarithmic	-544.044		$\log Q_t$	-1.1704	-0.0300
		t		(-3.2127)	(-0.3766)
	-542.490			-24.060	-0.1383
BC		t	$Q_t(\lambda)$	(-10.052)	(-0.2403)
		ε			(-0.0186)
		λ (0.30)			(0.30)
GBC			$Q_t(\lambda)$		

[a] L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b] DW for Durbin-Watson statistics.

[c] df for degrees of freedom.

RCP_{i-3}	FCR_i	R^2	DW^b	df^c
334.53	125.30	0.9491	1.2037	80
(3.1731)	(26.249)			
(0.2642)	(2.2684)			
0.2862	2.3238	0.9552	1.7144	80
(3.6284)	(28.323)			
2.3300	7.6217	0.9562	1.5891	80
(3.5225)	(28.413)			
(0.2733)	(2.2876)			
(0.30)	(0.30)			

Table 7.12. Broiler supply with broiler feed price ratio lagged three quarters and current feed conversion ratio

Model	L_{max}[a]		Dependent	Intercept	$BFPR_{i-3}$
	-555.122			-2814.8	70.052
Linear		t	Q_t	(-9.1623)	(1.0527)
		ε			(0.0878)
Logarithmic	-550.443		$\log Q_t$	-0.2793	0.0494
		t		(-0.9678)	(0.6019)
	-548.521			-25.079	0.5979
BC		t	$Q_t(\lambda)$	(-10.145)	(0.7536)
		ε			(0.0598)
		λ	(0.34)		(0.34)
GBC			$Q_t(\lambda)$		

[a] L_{max} for value of the log likelihood function
t for t-ratios
ε for elasticities evaluated at mean values
λ for transformation parameters.

[b] DW for Durbin-Watson statistics.

[c] df for degrees of freedom.

FCR_i	R^2	DW^b	df^c
114.41	0.9427	1.0737	81
(32.707)			
(2.0713)			
2.1126	0.9478	1.4944	81
(34.057)			
8.1450	0.9493	1.3774	81
(34.675)			
(2.0823)			
(0.34)			

expected to have a negative sign. Their significance levels are generally higher.

Therefore, it is concluded that the model which seems to best explain the broiler supply is in the following form:

$$Q_t = f(BFPR_{t-1} \quad FCR_t \quad Q_{t-1}) \tag{7.3}$$

This model provides the basis that there is enough flexibility in the hatchery supply flock to adjust the level of egg utilization for hatching for broiler producers according to changing situations in the broiler market, because it takes about 9 months to substantially increase egg productions. The estimation results for Equation 7.3 are presented in Table 7.2. All the estimates of the coefficients in any model for Equation 7.3 have correct signs as expected. Therefore, all discussions are based on the information contained in Table 7.2.

Since the linear, logarithmic and BC models are subfamilies of the GBC model, and since the same data are used in the computation process, the values of the log likelihood functions for the different models will be used as a test criterion to find the best model. The estimation results demonstrate that the value of the log likelihood function increases with less restrictions on the functional form. The value of the log likelihood function is maximized at -535.715 when the functional form is the GBC. Here again, the GBC model can be compared to all other models, because the GBC model corresponds to the unconstrained maximum. The linear and logarithmic models relative to the GBC model have four restrictions, respectively: (1) $\lambda_o = 1$ or 1, (2) $\lambda_o = \lambda_1$, (3) $\lambda_o = \lambda_2$ and

(4) $\lambda_o = \lambda_3$. The BC model has three restrictions: (1) $\lambda_o = \lambda_1$, (2) $\lambda_o = \lambda_2$ and (3) $\lambda_o = \lambda_3$.

The likelihood ratio tests will be employed to test the null hypothesis about the functional form of the broiler supply. The first test is about the null hypothesis that the functional form of the broiler supply is in either the linear or logarithmic model. The critical region for a likelihood ratio test of the null hypothesis at the significance level α is:

$$2[L_{max}(\lambda_i) - L_{max}(\text{all } \lambda_i\text{s} = 1 \text{ or } 0)] > \chi^2_\alpha(4) \qquad (7.4)$$

The second test is about the null hypothesis that all $_i$s are equal. The critical region at the α significance level for a likelihood ratio test of the null hypothesis is

$$2[L_{max}(\lambda_i) - L_{max}(\text{all } \lambda_i\text{s are equal})] > \chi^2_\alpha(3) \qquad (7.5)$$

The three tests are summarized in Table 7.13 with the critical values of chi-square distribution at the 0.05 significance level and the test statistics.

Therefore, the null hypothesis that the functional form of the broiler supply is either the linear or logarithmic is rejected at the 0.05 significance level. The null hypothesis that all the transformation parameters for each variable are equal is also rejected at the 0.05 significance level. Thus, the GBC model is significantly different at the 0.05 level from the linear, logarithmic and BC models.

Table 7.13. Likelihood ratio tests for functional form

Models compared	Value of test statistic	Critical value
GBC - linear	11.628	9.49(4)[a]
GBC - logarithmic	16.922	9.49(4)
GBC - BC	8.802	7.81(3)

[a]The values in the parentheses indicate degrees of freedom.

According to the calculated Durbin-h statistics, the null hypothesis that there is no autocorrelation is rejected at the 0.05 level for all models, except for the GBC model. Since an incorrect specification of the functional form between the variables is one of the causes of autocorrelated residuals, the Durbin-h statistics show that the GBC model must be of a better specification than the linear, logarithmic and BC models.

With respect to R^2, all the models have a high degree of fit, which is higher than 0.95, but the GBC model has the highest of 0.9632. Based on the values of the log likelihood functions, and on the tests about the functional form and autocorrelation, it is concluded that the GBC model best explains the broiler supply function. Therefore, an interpretation of the estimates of the coefficients in the GBC model will follow with comparisons to other models.

The estimated coefficients of all the variables in each model have correct signs as expected. The estimates of the feed conversion ratio and lagged dependent variables are highly significant at the 0.01 level in each model. The estimation of the broiler feed price ratio is significant at the 0.05 level in each model, and most significant in the GBC model. The significance level of intercept terms varies greatly among the models: significant at the 0.01 level in the linear and BC models, significant at the 0.05 level in the GBC model and significant at the 0.20 level in the logarithmic model. The short-run elasticities of broilers with respect to the broiler feed price ratio, evaluated at the mean values, are 0.140, 0.163, 0.147 and 0.078137 for the linear, logarithmic, BC and GBC models, respectively. Assuming that the GBC model is used as a discrimination tool, the elasticities are overestimated by 79 percent, 109 percent and 88 percent in the linear, logarithmic and BC models, respectively. This indicates that the future supply of broiler production will be overestimated if the estimated results from the models of the linear, logarithmic and BC models are used for forecasting purposes. It should be noted that the calculated short-run elasticities with respect to the broiler feed price ratio are smaller than the elasticities with respect to the broiler price in each model. This is partly due to the fact that the prices of the some inputs used in broiler production such as wage rate are excluded in the broiler supply function in this study.

The calculated long-run elasticities are 0.285, 0.239, 0.255 and 0.0781371 for the linear, logarithmic, BC and GBC models, respectively. If the GBC model is used as a discrimination tool, the elasticities are overestimated by 265 percent, 206 percent, and 226 percent for the linear,

Table 7.14. Supply elasticity of broiler and the response of supply elasticity with respect to feed conversion ratio

	Linear	Logarithmic	BC	GBC
Short-run elasticity (η_{SR})	0.140	0.163	0.147	0.078137
Long-run elasticity (η_{LR})	0.285	0.239	0.255	0.0781371
$\frac{\partial\eta_{SR}}{\partial FCR}$	-0.003	N.A.[a]	-0.002	-0.002
$\frac{\partial\eta_{LR}}{\partial FCR}$	-0.013	N.A.	-0.008	-0.002

[a]N.A. means "not available."

logarithmic and BC models, respectively. As economic theory suggests, broiler producers are more responsive to price in the long run than in the short run in the linear, logarithmic and BC models. However, both elasticities of short run and long run are almost the same in the GBC model, but the long-run elasticity is slightly higher than the short-run elasticity. The long run elasticities with respect to the broiler feed price ratio are also smaller than the long-run elasticities with respect to broiler price in each model. These results suggest that broiler producers are more sensitive to the broiler price rather than the broiler feed price ratio, even if the broiler feed price ratio has been important as a guide to producers.

The effects of an improvement of the feed conversion ratio on the short-run supply elasticity with respect to broiler feed price ratio are -0.003, -0.002 and -0.002 for the linear, BC and GBC models, respectively. In all three models, an improvement of the feed conversion ratio reduces the short-run supply elasticity. The effects on the long-run supply elasticity are -0.013, -0.008 and -0.002 for the linear, BC and GBC models, respectively. The effects on the short-run elasticity are almost similar in the three models, but the effects are significantly different from each other in the long run. These results suggest that broiler producers become less responsive to the broiler feed price ratio as feeding efficiency increases. These also demonstrate that with an increase in feed efficiency, the broiler supply function becomes steeper, while moving to the right. The GBC model suggests that a numerical one unit increase in the feed conversion ratio is related to a decrease in the broiler supply elasticity with respect to broiler feed price ratio by 0.2 percent over the sample period of 1960 to 1980.

B. Structural Evaluation

Two analyses will be presented for a possible change in the structure of broiler supply: one is for a possible change between periods and another for a possible change among quarters. Only the GBC model will be employed to evaluate a possible change in the supply structure of broilers, since the GBC model best explains the broiler supply. The first analysis in an effort to find a possible change in the supply structure of broilers is made by adding a dummy variable to allow a change in intercept and slope, instead of estimating two separate equations by dividing periods.

The equation used is:

$$Q_t(\lambda_o) = \beta_o + D + \beta_1 BFPR_{t-1}(\lambda_1) + \beta_1'[D \cdot BFPR_{t-1}(\lambda_1)]$$

$$+ \beta_2 FCR_t(\lambda_2) + \beta_3 Q_{t-1}(\lambda_3) \qquad (7.6)$$

where $D = \begin{cases} 0 \text{ for 1960-72, and} \\ 1 \text{ for 1973-80.} \end{cases}$

The values of λ_i in Table 7.2 are directly applied to Equation 7.6. The reason for dividing the sample period by 1960-1972 and 1973-1980 was given in Chapter 6. The estimation results are presented in Table 7.15 with t-ratios placed below estimates of coefficients. In model A, only a dummy variable is added to Equation 7.3 for a possible change in the intercept between periods. In model B, a dummy variable to allow a change in the slope is added. In model C, two dummy variables are added for a simultaneous change in both the intercept and slope. All three models have a high degree of fit in terms of R^2, which is higher than 0.96. The calculated Durbin-h statistics indicate that there is no autocorrelation at the 0.05 significance level in all three models.

In model A, all the variables have correct signs, and are significant at the 0.05 level, except for the dummy variable. The estimated coefficient of the dummy variable is significant at the 0.1 level. The negative sign of the dummy variable implies that the broiler supply curve shifts downward between the sample periods. In model B, all the variables, except $D \cdot BFPR_{t-1}(\lambda_1)$, are significant at the 0.05 level with

Table 7.15. Structural change of broiler supply between periods

Model	Dependent	Intercept	D	$BFPR_{t-1}(\lambda_1)$	$D \cdot BFPR_{t-1}(\lambda_1)$
A	$Q_t(\lambda_o)$	-80236.0	-20.540	695980.0	
		(-2.3071)[c]	(-1.6582)	(2.3268)	
B	$Q_t(\lambda_o)$	-80253.0		696120.0	-181.56
		(-2.3706)		(2.3273)	(-1.6582)
C	$Q_t(\lambda_o)$	-118530.0	47299.0	1034200.0	-418250.0
		(-1.5401)	(0.55438)	(1.5213)	(-0.55462)

[a]h for Durbin-h statistics.

[b]df for degrees of freedom.

[c]Values in parentheses are t-ratios.

$FCR(\lambda_2)$	$Q_{i-1}(\lambda_3)$	R^2	h[a]	df[b]
383.56	0.0000009 3071	0.9644	0.74391	79
(12.674)	(7.4135)			
383.56	0.0000009 3071	0.9644	0.74393	79
(12.673)	(7.4135)			
388.30	-0.0000009222	0.9646	0.80674	78
(12.297)	(7.2600)			

expected signs. The estimated coefficient of $D \cdot BFPR_{t-1}(\lambda_1)$ is significant at the 0.1 level with negative sign, implying that the broiler supply function becomes steeper in 1973-1980 period, when compared with 1960-1972 period. In model C the estimates of the coefficients D and $D \cdot BFPR_{t-1}(\lambda_1)$ are not significant even at the 0.1 level. This suggests that there is no statistically significant change in both the intercept and the slope of the broiler supply function between two segmented periods. But the negative signs of the estimated coefficients of $D \cdot BFPR_{t-1}(\lambda_1)$ in models B and C indicate that broiler producers become a little less responsive to price over time.

The second analysis is presented in order to find a possible structural difference of the broiler supply among quarters by adding a 0-1 dummy variable for each quarter to Equation 7.3.

The equation used is:

$$\begin{aligned} Q_t(\lambda_o) = {} & \beta_o + D2 + D3 + D4 + \beta_1\, BFPR_{t-1}(\lambda_1) + \beta_1'\,[D2 \cdot BFPR_{t-1}(\lambda_1)] \\ & + \beta_1''\,[D3 \cdot BFPR_{t-1}(\lambda_1)] + \beta_1'''\,[D4 \cdot BFPR_{t-1}(\lambda_1)] \\ & + \beta_2\, FCR_t(\lambda_2) + \beta_3\, Q_{t-1}(\lambda_3) \end{aligned} \tag{7.7}$$

where $D2 = \begin{cases} 1 & \text{for the second quarter,} \\ 0 & \text{otherwise} \end{cases}$

$D3 = \begin{cases} 1 & \text{for the third quarter,} \\ 0 & \text{otherwise} \end{cases}$

$$D4 = \begin{cases} 1 & \text{for the fourth quarter,} \\ 0 & \text{otherwise.} \end{cases}$$

The values of the transformation parameters of λ_o, λ_1, λ_2, and λ_3 come from Table 7.2. The estimation results for models D, E and F are shown in Table 7.16 with the t-ratios below the estimates. All three models have a high degree of fit with respect to R^2 which is higher than 0.98. According to the calculated Durbin-h statistics, the null hypothesis that there is no autocorrelation is rejected at the 0.05 significance level for all three models. Thus, an autoregressive model is estimated again after transforming the data with proper value of transformation parameter for each variable. The estimation results for models G, H and I are presented in Table 7.16. One kind of dummy variable for a possible difference in either the intercept or slope for each quarter is employed in models G and H. In model I, two kinds of dummy variables are employed to allow a simultaneous change in both the intercept and slope. All models have a high degree of fit. The values of the autoregressive coefficient, $\hat{\rho}$, are 0.90447 for the models G and H, and 0.47603 for the model I. They are significantly different from zero at the 0.05 level in any model. The notable difference between the GBC model and the GBC-Autoregressive model is that two models out of three autoregressive models have negative estimated coefficients of the lagged dependent variable.

In model G, the estimated coefficients for D2 and D3, are highly significant at the 0.01 level, but are not statistically significant

Table 7.16. Quarterly structure of broiler supply function: 1960-1980

Model	Dependent	Constant	D2	D3	D4
D	$Q_t(\lambda_o)$	-48262.0	47.918	26.097	-17.866
		(-2.1956)[a]	(7.9997)	(4.1639)	(-2.8916)
E	$Q_t(\lambda_o)$	-48258.0			
		(-2.1954)			
F	$Q_t(\lambda_o)$	1530.6	-0.3888	-189610.0	-107780.0
		(0.0588)	(-0.5771)	(-3.2844)	(-2.4436)
G (auto)	$Q_t(\lambda_o)$	-35523.0	49.721	49.831	3.1227
		(-1.9684)	(14.467)	(9.5054)	(0.6686)
H (auto)	$Q_t(\lambda_o)$	-35520.0			
		(-1.9682)			
I (auto)	$Q_t(\lambda_o)$	-660.52	-33272.0	-157780.0	-88837
		(-0.0293)	(-0.6504)	(-3.4418)	(-2.8140)

[a]Values in parentheses are t-ratios.

$BFPR_{t-1}(\lambda_1)$	$D2 \cdot BFPR_{t-1}(\lambda_1)$	$D3 \cdot BFPR_{t-1}(\lambda_1)$	$D4 \cdot BFPR_{t-1}(\lambda_1)$
415190.0			
(2.1373)			
415160.0	423.54	230.68	-157.89
(2.1371)	(7.9998)	(4.1462)	(-2.8912)
-24268	344080	1676100.0	952450
(-0.1055)	(0.5779)	(3.2848)	(2.4432)
292060.0			
(1.8309)			
292030	439.46	440.44	27.605
(1.8308)	(14.467)	(9.5061)	(0.6688)
-6661.7	294530.0	1394800.0	785070
(-0.0335)	(0.6514)	(3.4425)	(2.8136)

Table 7.16. continued

$FCR(\lambda_2)$	$Q_{t-1}(\lambda_3)$	R^2	h^b	$\hat{\rho}^c$	df^d
333.96	0.00000008	0.9876	3.1136		77
(19.776)	(12.280)				
339.96	0.00000099	0.9876	3.1136		77
(19.776)	(12.280)				
324.65	0.0000011	0.9895	3.3610		74
(19.239)	(13.560)				
581.10	-0.00000017	0.9905		0.90447	
(10.266)	(-0.99256)			(19.4344)	
581.09	-0.00000017	0.9905		0.90447	
(10.266)	(-0.9925)			(19.4348)	
364.86	0.00000087	0.9912		0.47603	
(14.708)	(7.7007)			(4.96098)	

[b] h for Durbin-h statistics.

[c] $\hat{\rho}$ for autoregressive coefficients.

[d] df for degrees of freedom.

for D4. Additional tests are made for equality of intercepts between the second and third quarters (i.e., D2 = D3), between the second and fourth quarters (D2 = D4), and between the third and fourth quarters (D3 = D4). The results are shown in Table 7.17. The tests reject the null hypothesis of D2 = D4, and D3 = D4 at the 0.05 level, but did not reject D2 = D3 at the same level. This implies that the intercept of the broiler supply function is not statistically different between the first and fourth quarters, and between the second and third quarters. In model H, the coefficient estimates of the $D2 \cdot BFPR_{t-1}(\lambda_1)$ and $D3 \cdot BFPR_{t-1}(\lambda_1)$, which are dummy variables for a possible change in the slope for the second and third quarters, respectively, from the first quarter, are statistically significant at the 0.01 level, but that of the $D4 \cdot BFPR_{t-1}(\lambda_1)$ not statistically significant. Additional tests are made for equality of the slopes between the second and third quarters [i.e., $D2 \cdot BFPR_{t-1}(\lambda_1) = D3 \cdot BFPR_{t-1}(\lambda_1)$], between the second and fourth quarters [$D2 \cdot BFPR_{t-1}(\lambda_1) = D4 \cdot BFPR_{t-1}(\lambda_1)$], and between the third and fourth quarters [$D3 \cdot BFPR_{t-1}(\lambda_1) = D4 \cdot BFPR_{t-1}(\lambda_1)$]. The results in Table 7.17 demonstrate that the slopes of the broiler supply function are not statistically different between the second and third parameters, but different between the second and fourth quarters, and between the third and fourth quarters. The results of the models G and H imply that the structure of the broiler supply function is not statistically different between the first and fourth quarters, and between the second and third quarters. However, the estimation result of the model I contradicts the

Table 7.17. Equality tests of intercepts and slopes among quarters

			F[a]	t[b]	df	df
For model G	Test	D2 = D3	0.001	-0.024	1	77
		D2 = D4	102.365	10.118	1	77
		D3 = D4	230.915	15.196	1	77
For model H	Test	D2 • BFPR(λ_1) = D3 • BFPR(λ_1)	0.001	-0.025	1	77
	Test	D2 • BFPR(λ_1) = D4 • BFPR(λ_1)	102.378	10.118	1	77
	Test	D3 • BFPR(λ_1) = D4 • BFPR(λ_1)	230.928	15.196	1	77
For model I	Test	D2 = D3	11.694		2	74
		D2 • BFPR(λ_1) = D3 • BFPR(λ_1)				
	Test	D2 = D4	96.590		2	74
		D2 • BFPR(λ_1) = D4 • BFPR(λ_1)				
	Test	D3 = D4	73.116		2	74
		D3 • BFPR(λ_1) = D4 • BFPR(λ_1)				

[a]F for calculated F statistics.

[b]t for calculated t statistics.

results of the models G and H. That is, the estimated coefficients of D4 and D4 • $BFPR_{t-1}(\lambda_1)$ are significant at the 0.01 level in model I, implying that the slope and the intercept are statistically different between the first and fourth quarters. The estimates of D3 and D3 • $BFPR_{t-1}(\lambda_1)$ are also significant at the 0.01 level. The equality tests of both in the intercept and slope between quarters in Table 7.17 indicate that the structure of the broiler supply function is different between quarters. These results are quite similar with those shown in Chapter 6.

C. Irreversibility of Broiler Supply

The broiler supply model with an assumption that the supply function is reversible has been estimated and discussed. In this section, the broiler supply model with an assumption of irreversibility will be estimated and analyzed. Following the techniques and procedures used in Chapter 6, two approaches will be employed by using the GBC model: one is the use of a dummy 0-1 variable and another segmentation of price variable.

The first approach is using a 0-1 dummy variable to allow for a change in the slope of the broiler supply with increasing and decreasing prices.

The equation used is:

$$Q_t(\lambda_o) = \beta_o + \beta_1 \cdot BFPR_{t-1}(\lambda_1) + \beta_1{}' [D \cdot BFPR_{t-1}(\lambda_1)]$$

$$+ \beta_2 \, FCR_t(\lambda_2) + \beta_3 Q_{t-1}(\lambda_3) \qquad (7.8)$$

where D = 1 for broiler-feed-price ratio increasing phase,

0 for broiler-feed-price ratio decreasing phase.

The values of the transformation parameters come from Table 7.2. The estimated result is:

$$Q_t(\lambda_o) = \underset{(-1.5635)}{-56858} + \underset{(1.5271)}{490550}\ BFPR_{t-1}(\lambda_1) + \underset{(1.9392)}{124.77}\ [D \cdot BFPR_{t-1}(\lambda_1)]$$

$$+ \underset{(12.895)}{355.47}\ FCR_t(\lambda_2) + \underset{(7.4134)}{0.00000091528}\ Q_{t-1}(\lambda_3) \qquad (7.9)$$

$$R^2 = 0.9649,\ \text{Durbin-h} = 1.4212,\ df = 79$$

The values in parentheses are t-ratios. Based on the calculated Durbin-h statistics, the null hypothesis that there is no autocorrelation is accepted at the 0.05 level of significance. All of the estimates of coefficients have expected signs. The addition of $D \cdot BFPR_{t-1}(\lambda_1)$ reduces the significance level of the estimates of the broiler feed price ratio. The estimated coefficient of $D \cdot BFPR_{t-1}(\lambda_1)$ is statistically different from zero at 0.1 level, implying that in the producers' response to the broiler feed price ratio there is a difference between the increasing and decreasing phases. The positive sign of $D \cdot BFPR_{t-1}(\lambda_1)$ indicates that the broiler producers are more responsive to the increasing phase of the broiler feed price ratio rather than the decreasing phase.

There is a difference between the increasing and decreasing phases.

Therefore, statistical estimation by segmenting the broiler feed price ratio into two variables is presented. Only the Wolffram's formulation is applied to split the broiler feed price ratio into two different phases (one for increasing and another for decreasing), based on the same reasonings as in Chapter 6.

The broiler supply model with an assumed irreversible relationship is:

$$Q_t(\lambda_o) = \beta_o + \beta_1 \cdot BFPRI_{t-1}(\lambda_1) + \beta_1' \cdot BFPRD_{t-1}(\lambda_1)$$

$$+ \beta_2 \; FCR_t(\lambda_2) + \beta_3 \; Q_{t-1}(\lambda_3) \qquad (7.10)$$

As shown above, the variable of the broiler feed price ratio is split into BFPRI for increasing phase and BFPRD for decreasing phase in order to test the irreversible phenomena of the broiler supply function with respect to broiler feed price ratio.

The estimated result is:

$$\underset{}{Q_t(\lambda_o)} = \underset{(-0.10069)}{-1953.1} + \underset{(2.2370)}{726430} \; BFPRI_{t-1}(\lambda_1) - \underset{(-2.3146)}{721300} \; BFPRD_{t-1}(\lambda_1)$$

$$+ \underset{(10.082)}{360.91} \; FCR_t(\lambda_2) + \underset{(4.6902)}{0.00000089119} \; Q_{t-1}(\lambda_3) \qquad (7.11)$$

$R^2 = 0.9631$, Durbin-h = 1.1807, df = 79

The values in parentheses are t-ratios. The calculated Durbin-h statistics accept the null hypothesis of no autocorrelation at the 0.05 significance level. The degree of fit is high. All the estimates of coefficients, except the intercept term, are statistically significant at the 0.05 level. The estimated coefficient of BFPRI is greater than that of BFPRD in absolute terms, implying that broiler producers are more responsive to the rising phase of broiler feed price ratio than to the falling phase. This result supports the irreversibility suggested by the fixed asset theory. However, the equality test of the coefficients of BFPRI and BFPRD in absolute terms is accepted at the 0.05 significance level. That is, the null hypothesis that there is no irreversibility in broiler supply function is not rejected at the 0.05 level. Even though broiler producers have a different responsiveness to rising and falling phases of the broiler feed price ratio, supporting the irreversible nature of the broiler supply or the implications provided by the fixed asset theory, their responsiveness is not statistically significant in differing from each other. This result is the same as the result in Chapter 6.

VIII. SUMMARY AND CONCLUSIONS

The purpose of this study is the construction of an econometric model to explain broiler supply at the producers' level in the United States. This study attempts to contribute to the knowledge of the influence of price and technology on broiler production in the United States. Therefore, the primary objective of this study is to find the magnitude of supply elasticity of broiler products, because the supply elasticity measures the producer's ability to adjust production to changing economic conditions. The elasticity parameter is useful in formulating public policies, and useful in helping farmers formulate better production decisions. The broiler industry has experienced a rapid expansion in its production. The expansion in broiler production can be explained largely by technological change, which is represented by the broiler feed conversion ratio in this study. Since output supply is affected by technological change, the second objective is to test whether the supply elasticity of broilers is decreasing with respect to the feed conversion ratio. There have been theoretical arguments in favor of an asymmetric supply response to increasing and decreasing prices. But the irreversible characteristics of the output supply function have generally been neglected in empirical studies. Therefore, the third objective is to test whether the broiler producers are more responsive to price rise than to price fall.

The choice of a functional form in empirical studies is a common practical problem. A common technique in statistical estimation of the agricultural supply function is to choose either the linear functional form or linear-in-logarithms functional form. The two functional forms may have some implications that are restrictive or inconsistent from the view of economic theory or actual behavior. Since there is no unique functional form for the supply function, which is suggested by economic theory, numerous attempts have been made in empirical studies of the agricultural supply function to find a better functional form in order to satisfy particular purposes. However, the work of Box-Cox and Box-Tidwell on the transformation of variables facilitates the use of a more general functional form to estimate the agricultural supply function. Their work shows that the linear and logarithmic functional forms are special cases of their general functional forms. Therefore, the use of Box-Cox and Box-Tidwell type regression equations provides a realistic advantage in empirical supply analysis since no knowledge exists on the functional form of supply from economic theory.

The broiler supply function in this study is expressed as a function of the broiler price, feed price, feed conversion ratio and lagged dependent variables. As an alternative method, the broiler feed price ratio is employed instead of both the broiler price and feed price. The specification is based on economic theory, broiler production patterns and the information from previous works. Estimations were performed using four different functional forms: (1) linear functional form, (2) linear-in-logarithms functional form, (3) a functional form with an application of the Box-Cox transformation to each variable with the same transformation parameter (BC model), and (4) a functional form with an application of the Box-Cox transformation to each variable with different transformation parameters (GBC model). Based on the values of the log likelihood functions, and on the tests about the functional form and autocorrelation, it is concluded that the GBC model is the best to explain the structure of broiler supply. The short-run price elasticity of broiler supply in the GBC model is 0.137 which is evaluated at the mean values. If the GBC model is used as a discrimination tool, other models of the linear, logarithmic and BC models overestimate the elasticity. This suggests that the future supply of broiler production will be overestimated if the estimated results from the other three models are used for forecasting purposes. The short-run elasticity of broiler supply with respect to the broiler feed price ratio is 0.078 in the GBC model. Therefore, the elasticity with respect to broiler price is greater than the elasticity with respect to broiler feed price ratio. This is partly due to the fact that the prices of some inputs used in broiler production such as the wage rate are excluded in this analysis.

The effect of an increase in the feed conversion ratio on the short-run price elasticity of broiler supply is -0.004 in the GBC model. This indicates that a numerical one unit increase in the feed conversion ratio is associated with a decrease in the supply elasticity by 0.004 or 0.4 percent over the sample period. The effect on the supply elasticity with respect to the broiler feed price ratio is -0.002. These suggest that with an increase in feeding efficiency, the broiler supply function becomes steeper, while moving to the right.

Structural evaluations are made by adding a dummy variable for a possible change in the intercept and slope of the broiler supply function between periods and among quarters. Estimation results suggest that there is no statistically significant change in both the intercept and slope of the broiler supply function between the period of 1960-1972 and the period of 1973-1980. Statistical tests for a possible change in the structure of the broiler supply among quarters demonstrate that both the intercept and slope are different among quarters. The slope of the broiler supply function is statistically different between the first and second quarters at the 0.1 significance level. The intercept and slope are statistically different at the 0.1 level between the first and third quarters, and between the first and fourth quarters. They are also different at the 0.05 level between the second and fourth quarters, and between the third and fourth quarters.

The broiler supply model with an assumption that the supply function is irreversible is estimated employing two approaches. The first approach is the use of a dummy variable to allow a possible change in the slope of the broiler supply function with rising and falling prices. Statistical results indicate that in the producers' response to price variables, there is a statistically significant difference between the price-increasing and the price-decreasing phases. Given the basis in the first approach, the broiler price and broiler feed price ratio are segmented into two variables (e.g., one for increasing phases and another for decreasing phases) in order to test the irreversible nature of the broiler supply function. The results imply that the broiler producers are more responsive to rising prices than to falling prices, supporting the implications provided by the fixed asset theory. However, the null hypothesis, that there is no irreversibility in the broiler supply function, is not rejected at the 0.05 significance level. This means that broiler producers have a different responsiveness to rising and falling prices, but their responsiveness is not statistically significant in differing from each other.

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XI. APPENDIX

Table 11.1. Basic data used in estimating the broiler supply function

Year	Quarter	Quantity of broiler produced in livewt. (in million pounds)	Broiler price per pound in livewt. at farm level (cents)	Feed price paid by producer per ton (dollar)
1959	I	1021	16.9	98.8
	II	1286	16.0	98.0
	III	1325	15.7	96.2
	IV	1046	15.7	93.8
1960	I	1099	17.6	93.8
	II	1352	17.5	93.4
	III	1446	16.7	92.4
	IV	1239	15.7	90.2
1961	I	1229	16.9	92.2
	II	1689	13.9	94.2
	III	1667	12.3	93.4
	IV	1339	13.1	91.6
1962	I	1278	16.4	93.0
	II	1674	14.4	93.0
	III	1594	15.6	93.4
	IV	1482	14.5	94.4
1963	I	1424	15.3	92.0
	II	1668	14.9	90.3
	III	1742	14.3	92.0
	IV	1527	13.9	91.3
1964	I	1547	14.2	91.7
	II	1771	13.8	91.0
	III	1771	14.7	90.3
	IV	1558	14.2	91.0
1965	I	1604	15.1	91.3
	II	1848	15.4	91.3
	III	1956	15.1	92.3
	IV	1767	14.5	90.7

Chick price paid by producers per 100 chicks (dollar)	Feed conversion ratio	Broiler feed price ratio	Implicit GNP deflator
10.67	32.1	3.4	66.98
9.15	32.3	3.2	67.45
9.59	32.6	3.2	67.70
10.24	32.8	3.3	67.95
10.40	33.0	3.7	68.42
11.73	33.3	3.8	68.55
12.30	33.5	3.6	68.81
12.67	33.7	3.4	68.94
12.37	34.0	3.6	68.85
10.01	34.2	2.9	69.18
8.92	34.5	2.6	69.48
9.04	34.7	2.9	69.59
9.91	35.0	3.5	70.17
8.82	35.2	3.1	70.41
10.22	35.5	3.3	70.60
10.83	35.7	3.1	71.03
10.87	36.0	3.2	71.32
9.92	36.3	3.1	71.37
9.66	36.5	3.0	71.58
9.92	36.8	2.9	72.07
9.41	37.1	3.1	72.28
8.95	37.3	3.0	72.53
9.35	37.6	3.3	72.93
9.65	37.9	3.1	73.08
9.85	38.1	3.3	73.68
9.78	38.4	3.4	74.06
9.78	38.7	3.3	74.56
9.60	38.9	3.2	74.92

Table 11.1. continued

Year	Quarter	Quantity of broiler produced in livewt. (in million pounds)	Broiler price per pound in livewt. at farm level (cents)	Feed price paid by producer per ton (dollar)
1966	I	1739	16.6	91.7
	II	2004	16.2	92.0
	III	2112	15.5	96.7
	IV	1971	12.9	96.0
1967	I	1910	14.5	95.0
	II	2175	13.6	93.7
	III	2180	13.3	93.3
	IV	1964	12.1	90.0
1968	I	1920	14.3	90.0
	II	2115	14.6	88.7
	III	2229	14.8	88.3
	IV	2047	13.2	88.3
1969	I	2065	14.7	88.3
	II	2336	15.4	90.7
	III	2390	16.6	92.0
	IV	2273	14.3	90.3
1970	I	2364	14.5	93.7
	II	2667	13.6	93.3
	III	2637	13.2	95.3
	IV	2405	12.4	98.7
1971	I	2422	13.5	99.0
	II	2593	14.4	99.7
	III	2685	14.6	98.0
	IV	2524	12.5	94.3
1972	I	2622	14.1	95.0
	II	2871	13.6	96.0
	III	2810	15.2	97.3
	IV	2655	14.2	104.7
1973	I	2587	20.1	127.0
	II	2768	24.4	148.0
	III	2765	31.3	171.3
	IV	2739	20.8	161.0

Chick price paid by producers per 100 chicks (dollar)	Feed conversion ratio	Broiler feed price ratio	Implicit GNP deflator
9.86	39.2	3.6	75.68
9.91	39.5	3.5	76.57
10.03	39.8	3.2	77.02
9.64	40.0	2.7	77.73
9.26	40.3	3.0	78.19
8.95	40.6	2.9	78.48
8.95	40.9	2.9	79.24
8.88	41.1	2.7	80.15
9.24	41.4	3.1	81.18
9.45	41.7	3.3	82.12
9.53	42.0	3.4	82.88
9.43	42.3	3.0	84.04
9.57	42.5	3.3	84.95
9.57	42.8	3.4	86.05
9.64	43.1	3.6	87.40
9.74	43.4	3.2	88.48
9.80	43.7	3.1	89.81
9.57	43.9	2.9	90.91
9.27	44.2	2.8	91.74
9.18	44.5	2.5	92.99
9.20	44.8	2.7	94.40
9.26	45.0	2.9	95.73
9.20	45.3	3.0	96.53
9.15	45.6	2.6	97.38
9.28	45.9	3.0	98.76
10.06	46.1	2.8	99.45
9.31	46.4	3.1	100.29
9.37	46.7	2.7	101.44
9.80	47.0	3.1	102.89
10.57	47.2	3.4	104.65
11.27	47.5	3.6	106.57
11.73	47.8	2.6	109.05

Table 11.1. continued

Year	Quarter	Quantity of broiler produced in livewt. (in million pounds)	Broiler price per pound in livewt. at farm level (cents)	Feed price paid by producer per ton (dollar)
1974	I	2730	22.4	168.0
	II	2923	20.2	152.7
	III	2851	21.4	171.0
	IV	2496	23.0	182.7
1975	I	2530	23.9	168.0
	II	2839	25.1	162.3
	III	2861	29.5	162.7
	IV	2752	26.5	160.7
1976	I	2922	24.6	159.3
	II	3189	24.1	164.0
	III	3277	24.0	179.0
	IV	3020	19.8	171.0
1977	I	2985	23.5	177.0
	II	3305	24.4	184.7
	III	3340	24.6	164.3
	IV	3110	21.4	157.3
1978	I	3226	24.2	164.3
	II	3519	28.7	171.3
	III	3540	28.0	169.0
	IV	3371	24.7	172.3
1979	I	3541	28.5	179.3
	II	3936	28.2	185.0
	III	3951	23.6	197.7
	IV	3683	23.8	194.7
1980	I	3759	25.6	193.3
	II	4027	23.5	190.7
	III	3796	31.8	208.7
	IV	3695	30.5	234.3

Chick price paid by producers per 100 chicks (dollar)	Feed conversion ratio	Broiler feed price ratio	Implicit GNP deflator
12.10	48.0	2.7	111.28
12.27	48.3	2.6	114.34
12.23	48.6	2.5	117.52
12.20	48.8	2.5	121.06
12.27	49.1	2.8	124.16
13.00	49.3	3.1	125.95
12.67	49.6	3.6	128.19
12.73	49.8	3.3	130.14
13.03	50.1	3.1	131.30
13.27	50.3	3.0	132.79
13.67	50.6	2.7	134.35
13.90	50.8	2.3	136.34
13.70	51.1	2.6	138.34
14.13	51.3	2.6	140.93
14.07	51.6	3.0	142.59
14.13	51.8	2.7	144.82
14.23	52.1	2.9	147.05
14.70	52.3	3.4	150.82
14.53	52.5	3.3	153.45
14.77	52.8	2.9	156.68
15.07	53.0	3.1	160.22
15.37	53.2	3.0	163.81
15.27	53.4	2.4	167.20
15.23	53.7	2.4	170.58
15.33	53.9	2.6	171.23
15.27	54.1	2.5	175.28
15.83	54.3	3.1	179.18
15.90	54.5	2.6	183.81