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Shunji Oniki

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R. J. Myers
Major professor

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EFFECTS OF OUTPUT CHANGES ON FACTOR DEMAND IN JAPANESE AGRICULTURE: A FLEXIBLE DYNAMIC COST FUNCTION APPROACH

By

Shunji Oniki

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ABSTRACT

EFFECTS OF OUTPUT CHANGES ON FACTOR DEMAND IN JAPANESE AGRICULTURE: A FLEXIBLE DYNAMIC COST FUNCTION APPROACH

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Shunji Oniki

Agricultural production in Japan is anticipated to contract due to import liberalization and this output reduction will chang input use for the production, such as labor and chemicals. This study explores effects of changes in output on factor demand through estimation of the factor demand equations and simulation of factor adjustment. In Japanese agriculture, factors are not likely to be adjusted instantaneously to their equilibrium levels due to high costs of adjustment, habits and customs, and time lags in the transmission of information. As a result, this study applies an error correction model based on share equations derived from a translog cost function. The model maintains the flexible properties of a translog function but also permits short-run disequilibrium. Estimation of the dynamic model shows that output elasticity of labor demand is greater than unity, while the elasticities of chemical and capital use are less than unity. It implies that, in the long-run, average use of chemicals per unit of output increases, and the labor required to produce a unit of output declines.

In order to incorporate the effects of changes in factor prices into the analysis of output effects, a short-term factor adjustment process is simulated. Simulation of long-run equilibrium adjustment of factor use shows that chemical use will decline little, while labor declines greatly. Simulation using the dynamic model of factor share adjustment also shows that shares of chemical and capital increase, while the share of labor declines. These results

are generally consistent with earlier findings on output elasticities.

To my parents.

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CHAPTER 1

INTRODUCTION

1.1 Problem Statement

The General Agreement on Tariffs and Trade (GATT) of 1993 requires all member countries to reduce tariff rates and non-tariff restrictions on agricultural commodities. In Japan, agricultural import liberalization will decrease demand for domestically produced commodities since prices of most agricultural commodities in Japan are several times higher than their international prices.[1] Policy makers are concerned how a reduction in domestic production will affect the structure of Japanese agriculture, and in particular, the environmental impact of a reduction in the use of agricultural chemicals, and the potential increase in an employment problem. However, little empirical research has been done on how changes in production affect input use in Japanese agriculture.

In order to explore the impact of output reductions induced by trade liberalization on the structure of Japanese agriculture, this study analyzes the effects of changes in output on factor demand. While many studies have analyzed the effects of changes in input prices on output supply using the production function linking inputs and output, there is currently little research on how output changes may affect the structure of input demand. For example,

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[1]Another factor is the rising value of the yen. For example, the Japanese yen rose about 50 percent in terms of the US dollar from 1990 to 1995.

although studies have evaluated the effects of environmental policies that restrict input use on total output,[2] few studies have estimated how a change in output would affect demand for an input that is harmful to the environment. However, because environmental issues and rural employment problems are of great policy importance, inputs, including agricultural chemicals and labor, have become important factors for policy analysis. Thus, it is important to develop quantitative measures of impacts of output changes on input demand.

1.2 Research Objectives

This study has three main objectives:

1. To estimate a dynamic factor demand model, using data on agricultural production and prices in Japan for the period from 1951 to 1992.
2. To develop estimates of elasticities of input demand with respect to output levels and input prices, as well as partial elasticities of factor substitution and the extent of biased technological change in Japanese agriculture.
3. To simulate factor use 10 years into the future under different scenarios as to how import liberalization would affect output levels and factor prices.

The first objective involves developing a dynamic model that is useful for carrying out a structural analysis of agricultural production where full input adjustment may not be assumed in the short run. The model is specified to be as flexible as possible in order to avoid a priori assumptions on factor substitution and production homotheticity. This allows hypotheses on the structure of production to be treated as testable rather than imposed a priori.

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[2]Dean (1993) provides a extensive survey of literature on this issue.

In the second objective the production structure is analyzed in terms of factor demand and bias in technological change. Although the primary interest of this study lies with the effect of output changes on factor demand, this output effect is closely related to substitution between factors and technological change. Therefore, it is important to analyze the whole structure of production. Analytical tools used for this purpose include output elasticities of factor demand, partial elasticities of factor substitution, own- and cross-price elasticities of factor demand, and elasticities of technological change bias.

While this structural analysis deals with long-run elasticities, and therefore long-run effects on factor demand, it is also interesting to consider the dynamic path of factor adjustment in the context of Japanese import liberalization policy. Thus, the third and final goal of the study is to simulate factor adjustment, using the long-run equilibrium model which allows for short-run disequilibrium. These simulations, in addition to estimation of the long-run output elasticity, will provide comprehensive insights about how output changes might affect factor use in Japanese agriculture.

1.3 Previous Studies of Aggregate Production Functions

Aggregate production function analyses have relied on economic theory and econometric models. In terms of economic theory, duality theory has played a major role in analyzing both of these aspects in recent years. Indeed, in the 1960s and the early 1970s, production function analysis has moved from direct estimation of production functions and first-order conditions to application of duality theory using Shephard's lemma and Hotelling's lemma.

In terms of econometric models, many different functional forms have been used in aggregate production function analysis. Before the 1960s, the Cobb-Douglas model was applied extensively. Advantages of this model include simplicity, its straightforward mathematical properties, and compatibility with actual data. In 1961, Arrow and others raised a question about flexibility of the Cobb-Douglas form and developed the constant elasticity of substitution (CES) model. Uzawa (1962) developed the multi-factor CES model. The CES and its variations have been applied in a number of empirical works. For example, studies of Japanese agriculture by Shintani and Hayami (1975), and Kawagoe (1986), applied the two-stage CES production function. Since the 1970s various other flexible models have also been used. One of the most widely used models is the translog developed by Christensen, Jorgenson and Lau (1971, 1973). Binswanger (1974a, 1974b) used a translog cost function in analyses of agricultural production in the United States and introduced a method to measure biased technological changes in the translog model. According to his estimation results, the usual assumption of neutral technological change was not supported by the data. Also, he found that elasticities of substitution are not constant across factors. These results showed that previous models, such as Cobb-Douglas and CES, were not valid and justified application of more flexible functional forms.

Technological change bias, a nonhomothetic production process, and factor price changes should all be incorporated in an analysis of production. In a generalized Leontief cost function study of Canadian agriculture, Lopez (1980) showed that a change in factor shares was not being caused by a technological change bias, but by output changes and factor price changes. Thus, he argues that if the assumption of a homothetic production process is imposed on the model, the effects of output changes are incorrectly attributed to biased technological change, even if technological progress is, in fact, Hick's neutral. This finding raised a question regarding the measurement of technological bias in models with restrictive functional forms that assume homotheticity. Binswanger implicitly imposed a homothetic production process when he measured technological change bias. Also, Ray (1982) imposed the assumption of Hick's neutral technical change when using a translog cost model of US agriculture. Assumptions in these studies may have led to misspecification and erroneous conclusions.

Economists have carried out many aggregate production function studies for Japanese agriculture, many of which evaluate technological change bias and productivity. These include pioneering works by Hayami and Ruttan (1970, 1971), Hayami (1973), and Shintani and Hayami (1975), which tested the induced innovation hypothesis initially suggested by Hicks (1934). Hayami and Ruttan (1970, 1971) and Kawagoe, *et al.* (1986) compared the paths of technological progress in Japan and in the United States. These authors found that, since land is a relatively scarce resource in Japan, a land-saving technology, such as high-yielding varieties, was developed. On the other hand, as labor was relatively scarce in the U.S., labor-saving technology, such as large-sized mechanization, was developed. Thus, by comparing development patterns in these distinct countries, they successfully characterized the direction of bias in technological innovations. However, the distinction between the two countries has recently diminished. In Japan, as the demand for labor rose in the industrial sector, it became a relatively scarce factor in rural areas as well. In the United States, the development of high-yielding varieties and application of fertilizers has accelerated as land has become more scarce.

Most studies using models with flexible functional forms have found the existence of both biased technological change and nonhomotheticity in production. For example, the generalized Leontief cost model by McLean-Meyinssee and Okunade (1988) found labor- and chemical-saving technological changes and nonhomotheticity in production process in Louisiana rice production.

Nghiep (1979) first applied the translog model to the study of Japanese agriculture. He imposed a homothetic restrictions in a production process. Kako (1979) used a translog cost model in his study of the total factor productivity, imposing a homothetic production process. Kuroda (1988) found that the assumption of homotheticity is invalid in Japanese agriculture. However, the data used in his study are questionable. For example, he used wages of hired labor as a proxy for wages in the total farm sector. However, hired labor in Japan accounts for only 2 percent of total agricultural labor and it may be hired by only large-scale farms.

In addition to the translog function, the model developed by Egaitsu and Shigeno (1983) was applied in several works, such as Nakajima (1989) and Ohe (1990). This model is a two-level production function. It assumes potential substitution between labor and machinery and between land and fertilizers but no substitution or complementarity between the other combinations of inputs.

In the past, studies on the aggregate production function for Japanese agriculture have not dealt explicitly with effects of output on factor demand. In terms of output effects, only economies of scale, which represent effects of output changes on total costs, have been analyzed.

The concept of an elasticity of scale was introduced by Hanoch (1965). This elasticity measures the proportional change in output as all inputs change at the same rate. Baumol *el al.* (1982) developed a method to evaluate how a change in output affects production cost in a multi-product production. They derived elasticities of total cost with respect to output, which explains whether an industry exhibits increasing, decreasing, or constant economies of scale. The elasticities of scale are estimated in translog studies, such as Murty, *et al.*(1993), Gyapong and Gyimah-Brempong (1988), Seldon and Bullard (1992), Hoche and Adelaja (1984), Chino (1985), and Kako (1979). Although the reciprocal of an estimated elasticity of scale represents how much input levels would change as the output level changes, this measurement must have the strong restriction that all inputs must change by the same proportion.

Production functions are also used in studies that measure effects of output changes on factor use.[3] In this case, estimated parameters of a production function are used to find the relationship between output and input levels. In the Cobb-Douglas production function, the reciprocal of a parameter on an input variable represents the elasticity of the output with respect to the input. When this measure is used to evaluate the effects of changes in output on factor demand, the model imposes another strong restriction that all input levels, other than the input of interest, remain unchanged. That is, only one input level is allowed to change when the output level changes; so that no factor substitution is permitted in the analysis. However, such an assumption is not realistic. Changes in output are usually associated with changes in the levels of all inputs. In order to examine the output effect on demand for inputs, it is important to include substitution effects. Instead of assuming that all inputs change by the same degree, or that only one input varies and other inputs are fixed, this study utilizes a method that permits all input to change.

So far we have only considered restrictions in static models. However, intertemporal effects should also be considered. A static model implicitly imposes the restriction that all

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[3]For example, Shintani's studies (1970, 1972, 1978) analyze input elasticities of output in Japanese agriculture.

changes in the variables of a model are resolved within a period (*e.g.*, one year). If production factors are adjusted over more than one period, this restriction is violated. However, dynamic econometric models which allow for slow adjustment have rarely been applied in Japanese agriculture. In his study on Japanese agriculture, Nghiep (1979) incorporated a partial adjustment process in share equations derived from the translog cost function. Although he did not test explicitly the dynamic structure of production, estimated parameters on the lagged share variables are statistically significant from zero, implying the assumption of short-run equilibrium may be inappropriate for Japanese agricultural production. However, there are very few other studies that have paid attention to the problem of dynamic adjustment.

There are several reasons that dynamic adjustment occurs in agricultural production. First, farmers may need time to obtain information, to learn new production practices, and to sell or buy assets. Also, since rapid adjustment of factors often requires high adjustment costs, the adjustment may be delayed. Thus, full cost minimization may not be achieved in the short-run. However, it is still reasonable to assume that the long-run equilibrium will be achieved in the long run. The model applied in this study is a dynamic model that allows short-run disequilibrium, but captures a long-run relationship between the variables. Thus, this study attempts to avoid prior assumptions imposed in past studies, such as instantaneous factor adjustment, as well as constant elasticities of substitution, homothetic production process, etc.

Besides modeling the dynamic factor adjustment process, this study extends previous studies on the aggregate production function in terms of output effects. A production function represents effects of factor price changes, effects of technological changes, and effects of output changes; yet, the output effects have been rarely evaluated in past empirical studies. These are explicitly expressed in this thesis as an elasticity of factor demand with respect to output.

Also, while knowledge of the long-run effects of output changes on factor demand is useful for a structural analysis of agricultural production, analysis on how each factor use changes due to output changes and factor price changes is often more useful for policy analysis. Elasticities used in a structural analysis of production assume that other factor prices and output remain constant. However, in the real world, changes in all factor prices, as well as output, affect factor use simultaneously. In order to consider how output changes caused by trade liberalization might affect factor use, this study carries out a simulation which incorporates effects of changes in factor prices associated with the output changes into the analysis of factor use. Simulated paths of factor adjustment over 10 year period are presented graphically. These simulations supplement the analysis of long-run effects by examining short-run dynamics and including the effects of price changes.

Overall, past studies of aggregate production have mainly focused on changes in output or productivity, with little attention being paid to changes in factors of production. However, changes in demand for factors, especially agricultural chemicals and labor, have become serious concerns in rural areas. Thus, it is important to develop a method for measuring these effects. Also, it is important to use a flexible functional form that accommodates nonhomotheticity and bias in technological change.

1.4 Outline of the Dissertation

The next chapter characterizes agricultural production in Japan in terms of trade policy and factor use. In Chapter 3, a quantitative model is developed. This chapter first discusses the theory of duality, functional forms and dynamic models. Then, based on these arguments, a dynamic econometric model is derived from a translog cost model. Chapter 4 discussed stationarity conditions. Stationarity of individual series and cointegration among the series are tested. Using estimates from the dynamic model, Chapter 5 evaluates elasticities used in structural analysis. Chapter 6 simulates factor adjustment associated with several different paths of output. In this chapter, a long-run equilibrium model provides paths of factor use in long-run equilibrium, and simulations with the dynamic model provide short-run adjustment paths of factor shares. Finally, Chapter 7 concludes and summarizes the policy implications of the analysis.

CHAPTER 2

PROBLEM SETTING

In order to better understand the background of this study, Chapter 2 characterizes Japanese agricultural policy and the structure of agricultural production. Japanese trade policy and the effects of the coming import liberalization for agricultural products are discussed first. Next, the characteristics of production factors are explained, followed by discussion of their implications for productivity. These arguments are useful for specifying a model of the agricultural production.

2.1 Agricultural Trade Protection and Rural Problems

Trade protection is defined as a policy which sets prices on the domestic market higher than those on the international market equilibrium by restricting imports. In this sense, Japanese agriculture has been highly protected for many years. For example, rice, which is the major agricultural product in Japan, had not been imported at all on a regular basis until 1996.[4] Government agencies also control all imports of wheat, butter, powdered milk, tobacco, and silk.[5] Thirteen products are imported under quotas (*i.e.,* quantity restriction).

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[4] However, rice was imported in several bad harvest years to eliminate shortages.

[5] Japan Ministry of Agriculture and Forestry, Ministry of Agriculture, Forestry, and Fishery, *Statistical Yearbook of Agriculture, Forestry and Fisheries*, Statistics and Information Department, Statistical Bureau, Ministry of Agriculture, Forestry, and Fisheries, Japan, various issues.

Under pressure from foreign countries, the Japanese government has been reducing these import restrictions over time. The number of products under import quotas decreased from 102 in 1962 to 22 in 1974.[6] In 1988, import quotas on nine products, including beef and citrus, were removed.

In December of 1993, the Uruguay Round of the General Agreement on Tariffs and Trade (GATT) determined that all member countries were to reduce tariff rates on agricultural products by 36 percent on average, and at least, 15 percent for an individual commodity after 1995.[7] The agreement determined that an option of minimum access could be granted to a country whose current imports of the commodity were less than 3 percent of domestic consumption, if the country did not implement export subsidies or other output enhancement programs. The amount of minimum access was set at 4 percent of domestic consumption in the first year. Then, the rate is to increase by 0.8 percent of consumption every year until the rate becomes 8 percent in the fifth year. The Japanese government will apply the minimum access option for rice imports. Thus, through tariff reduction and the minimum access policy, imports of agricultural products will increase.

Agricultural protectionism in Japan is generally thought to be created by political forces. With people in rural areas rapidly moving into urban areas in the last few decades, regional imbalances of political representation have been created. Institutional changes in the election system have lagged the continuous migration of population. In some rural areas, the number of representatives in the National Diet (Congress) per person are more than twice the

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[6]Japan Ministry of Agriculture, Forestry, and Fishery, *op.cit.*

[7]Non-tariff restrictions were converted into tariffs.

average. Thus, political power in rural areas remains relatively strong and the agricultural sector has become protected.

However, persistent agricultural protectionism in Japan cannot be explained only by the imbalance of the election system. Hayami (1986) argued that the level of agricultural protection is determined by political benefits and costs of a policy.[8] A politician would gain support from farmers by implementing a protective policy, while losing support from consumers. Relative protection levels are then chosen so that net political benefit is maximized. With the development of the industrial sector, farmers find that their incomes decline compared to the industrial sector. Then, political activities by the farmers become intense and politicians' marginal benefits from agricultural protection is increased. On the other hand, as the economy advances and consumers' incomes rise, they become less concerned with the price of food. Thus, the level of agricultural protection increases along with economic development. This hypothesis is also supported by a cross-country econometric study by Homma and Hayami (1986), which revealed that there is a general tendency for agricultural policies to become more protective as national incomes increase.

There are other arguments that non-monetary factors may affect protectionism. The non-monetary factors can be categorized as: (i) concerns about national food security, (ii) support of rural society and the agricultural community, (iii) uncertainty about food safety of imported rice, and (iv) preservation of rural landscapes and water systems.

In Japan, the proportion of the domestic food supply in total food consumption (*i.e.*, the

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[8]This argument follows theories of political economy proposed by Buchanan and Tullock (1962), and Breton (1974).

food self-sufficiency ratio) has been decreasing during the last thirty years. From 1965 to 1992, the self-sufficiency ratio dropped from 73 percent to 46 percent of the calorie base; from 86 percent to 65 percent of the total value of food, and from 62 percent to 29 percent of the total value of grains.[9] Yet, the decrease in self-sufficiency does not necessarily imply a decrease in national food security. As food security is defined as a stable supply of food, depending on international supply does not necessarily increase risk and uncertainty in the food supply. There is no evidence to show that the international rice market is so risky as to justify the complete self-sufficiency of rice in Japan.[10]

With regard to supporting rural society and the agricultural community, urban consumers may be willing to pay a higher price for food to support farmers' income. In the case, some trade protection, rather than free trade, may be a rational policy both farmer and consumer utility would be higher with the protection. Import liberalization would reduce consumer utility as well as producer utility.[11]

This issue is closely related to social problems in rural areas of Japan. In the last forty

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[9]Japan Ministry of Agriculture and Forestry, Ministry of Agriculture, Forestry, and Fishery, *Statistical Yearbook of Agriculture, Forestry and Fisheries*, Statistics and Information Department, Statistical Bureau, Ministry of Agriculture, Forestry, and Fisheries, Japan, various issues. The total value of grain includes feed grain for livestock.

[10]Hayami (1985b) explained in detail the reasons why import restrictions could not be justified by concerns about food security.

[11]According to Sen (1990), altruism occurs as one wants to satisfy a feeling to help others, therefore, it is a sort of self-interest. Note that Sen (1990) distinguished "commitment" from "altruism." With commitment, an individual acts voluntarily to help others. Unlike altruism, a result of action under commitment would not affect the person's utility, as he does just for his sense of duty. For example, if a country refuses to import from another country that infringes certain human rights, it is considered as a commitment. However, this is not the case of Japanese import restriction.

years, the rural sector experienced a rapid decrease in population, especially among the young generation. This situation biased demographic patterns in the rural area. The rural sector now consists of a high ratio of elderly people compared to young people. As a result of the decrease in rural population, funds for public services, such as education, medical service, and infrastructures, have become scarce and business opportunities have decreased. These developments have accelerated migration out of the rural areas.

Environmental problems may also influence agricultural protection. In general, agricultural production has both negative and positive effects on the environment (Sakurai, 1993, and Ogura, 1990). The negative effects include contamination of soil and water, soil erosion, and exploitation of water resources. Contamination of water in rivers, lakes, and groundwater have come to be a serious environmental issue, because a large amount of chemical input is used in crop production (Kumazawa, 1995). On the other hand, soil erosion is not a serious problem in Japan, since paddy rice production prevents soil erosion. On the positive side, agricultural production, especially rice production, contributes to the preservation of water resources and land, provides aesthetic values of rural landscape, and preserves biological resources (Mitsubishi Research Institute, 1991).[12] In addition, consumers are concerned with the safety of imported agricultural products, since it is difficult to monitor

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[12]According to a hedonic study of Mitsubishi Research Institute, the total environmental benefits of rice production in Japan is $120 billion per year. Also, in a contingent valuation study for more aggregated values (*i.e.,* total WTP for protecting the landscape and natural resources), Fujimoto estimated the total external value of Japanese rice production in Nara Prefecture to be $439 million. A hedonic study of Urade *et al.*(1992) found that the total economic values of the agricultural and forestry resource is $20 billion each year. Yoshida (1995) estimated an economic value of the landscape of a agricultural area--Miou, Hokkaido using the contingent valuation method. The estimated values are $150 for a resident and $80 for a visitor.

pesticide residues on imported food and many kinds of pesticides and other agricultural chemicals are used in the world.

Protective trade policy is based on various problems related to rural society and the environment. Such problems are related to production factors, such as labor, agricultural chemicals, and farmland. Therefore, through changes in the production factors, changes in the trade and agricultural policies influence social and environmental problems. These factors have important implications for rural areas. The characteristics of these production factors are explored in the next section.

2.2 Inputs in Japanese Agriculture

This section explains characteristics of production factors and related institutional and technological issues that may affect factor adjustment. The descriptive analysis facilitates an understanding of the adjustment mechanism.

Land

A large portion of the land in Japan is mountainous and there is only a small amount of arable land. In 1993, the area of land used for agriculture was 5.2 million hectares or 14 percent of the total area of Japan.[13] Rice accounts for 51 percent of the total area of crop cultivation, followed by vegetables with 15 percent, fruits with 8 percent, and wheat with 7 percent.

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[13]The agricultural land includes 1.1 million hectares of pasture.

Land is so limited in Japan that the productivity in marginal areas can be low. There are many terraced fields in the mountains, and these fields are the least productive. Farmland is small and irregularly shaped so it is difficult to use large machinery. Also, when the size of an individual farm increases as the aggregate output level increases, then there are economies of scale in production. In Japanese agriculture, the production technology, in terms of use of factors, varies according to the size of a farm. Table 2.2.1 shows production costs per hectare in 1992 for each input category. Labor costs per hectare decrease greatly as farm size expands. Labor cost per hectare for a farm with more than 5 hectares was 42.8 percent lower than an average-sized farm. Costs per hectare for chemical inputs (*i.e.,* fertilizer and pesticides) decrease by 82.5 percent and costs per hectare for machinery decreases by 70.1 percent for large farms compared to the average. The total cost per hectare in a farm with more than 5 hectares was 67.1 percent of the average. These data show economies of scale in rice production. The proportion of cost savings for a large farm is the highest for labor costs, followed by machinery, and chemical inputs.

Until 1965, production costs per hectare for farms for farms with more than 3 hectares of farmland were almost the same as the costs per hectare with less than 0.3 hectares. Yet, in the 1970s, the former became approximately one half of the latter.[14] However, as farm size expanded beyond a certain level, yield declines, so that the cost reduction due to economies of scale was offset by a decrease in income due to lower yield. In terms of rice production,

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[14]Japan Ministry of Agriculture and Forestry, Ministry of Agriculture, Forestry, and Fishery, *Survey on Production Cost of Agricultural, livestock and Sericultural Products* (Tokyo: Statistics and Information Department, Statistical Bureau, Ministry of Agriculture, Forestry, and Fisheries, Japan).

Table 2.2.1 Production Costs of Rice by Farm Size per Hectare, 1993, Japan

	Average	0.3 -0.5ha*	0.5 -1.0ha	1.0 -1.5ha	1.5 -2.0ha	2.0 -3.0ha	3.0 -5.0ha	5.0+ ha
Fertilizer	91.52	104.22	99.38	87.14	79.41	88.04	93.06	82.81
Other chemical	73.08	78.24	76.35	75.26	66.89	73.33	69.11	64.06
Infra -structure	83.38	182.76	94.69	74.77	90.71	76.63	85.98	78.57
Rents, Fees	109.57	200.96	145.09	100.11	79.83	68.84	57.51	48.26
Machinery	266.63	285.13	299.57	274.45	270.08	246.23	233.62	184.80
Labor	561.56	769.17	679.93	578.30	487.27	452.57	405.04	327.91
Total	1,185.74	1,511.42	1,395.01	1,190.03	1,074.19	1,005.64	944.32	786.41

*ha: hectare

Source: The Japan Ministry of Agriculture, Forestry and Fisheries, *Survey on Production Costs of Agricultural, Livestock and Sericultural Products*.

the yield of a farm with more than 5 hectares was 4.4 percent lower than a farm between 3 and 5 hectares[15]. While the cost of rice production per hectare for a farm of more than 5 hectares was 8.8 percent lower than a 3-5 hectare farm in 1993, due to the lower yield the farm gross income was 1.6 percent lower and the net profit was 9 percent lower.[16] Thus, farmers' net incomes were not higher for a large-scale farm.

The size of farms did not increase for a long period of time in Japan. In Table 2.2.2, 80 percent of the rice farms were less than 1 hectare in 1990, while only 5 percent of the farms were larger than 2 hectares. The reason that farm size has remained small is explained by the fact that farmers have kept their farmland as assets for future investments. Due to the regional development policies of the 1960s and 1970s, Japanese land prices increased rapidly. Thus, farmers expected the price of their farmland to continue to rise in the future. This argument, however, does not explain why land transfer remains low even when the price has declined. Another explanation is that economies of scale could not be achieved even if small, scattered farmland was gathered.[17] Therefore, farmers did not expand their farm size. Since there are many small plots of farmland, it is difficult to collect a large area of land in the neighborhood. Even if farmland could be collected, additional investment in infrastructure is required. Such a large-scaled investment can be done only by a large farmer who has enough funding and productive resources. If a farmer owns farmland in several separated

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[15]*op. cit.*

[16]The net profit is the gross income minus total production costs and family labor and rents to land owner.

[17]"Economies of size" means, in this section, decreasing average cost per hectare.

Table 2.2.2 Number of Farms by Size in Japan, 1950-1990 (thousands)

	0-0.5 ha*	0.5-1.0 ha	1.0-2.0 ha	2.0-3.0 ha	3.0-5.0 ha	5.0 ha and over
1950	1,032	1,952	1,308	176	26	1
1955	1,006	1,955	1,357	179	28	2
1960	992	907	1,406	201	34	2
1965	954	1,762	1,352	215	38	2
1970	910	1,619	1,281	244	57	6
1975	865	1,436	1,076	236	57	9
1980	806	1,304	980	240	82	13
1985	753	1,182	883	234	93	19
1990	765	1,049	782	222	100	26

*hectare

Source: The Japan Ministry of Agriculture, Forestry and Fisheries, *Agricultural Census* places, it is difficult to exploit economies of scale by using large-sized machinery. Diseconomies of size might even occur if additional costs for transportation and management are required.

A third explanation is that the land law enacted after the war restricted the transfer of farmland. The land reform, which was a part of agricultural reform immediately after World War II, was carried out by the postwar government under strong recommendation of the U.S. General Headquarters Organization[18]. The objective of the land reform was to end the old landlordism and to stabilize the rural society. The government purchased 1.9 million hectares of farmland and sold it to tenants at very low prices. As a result, the proportion of the number of tenants to total farmers declined from 45 percent to 9 percent during the 1945-55 period (Hayami and Ruttan, 1985). The Land Law of 1952 legally supported the land reform and the rights for tenancy were strengthened. All land owned by absentee landlords and landlords exceeding 1 hectare was purchased by the government, and transfer of farmland was restricted. This land law was revised in 1962 and 1970 and the restrictions on land transfer were liberalized in the new laws. Therefore, the transfer of farmland is no longer a significant obstacle.

Technology in Japanese agriculture developed under a severe constraint on available farmland. The land constraint induced innovation of land-saving technologies, such as introduction of new varieties responsive to fertilizers and increased yield. Innovations in land-saving technology should reduce the price of land but prices have increased rapidly since the 1960s. Tsuchiya (1988) argued that increasing land prices were caused by the general

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[18]Kawano (1970), p. 374

development of agricultural technology. Since technological development reduced the marginal cost of production, the agricultural sector grew as more farmers entered production. Thus, demand for agricultural land increased and, therefore, the price of farmland increased. Still, this argument is not strong enough to explain why land prices rose even when agricultural production declined. Rather, it seems that land prices were raised due to the development of rural areas in Japan beginning in the mid-1960s when regional development policies were implemented. Markets for farmland are not independent of markets for land used for other purposes.

To sum up, even though economies of size exists at the sector level, sizes of individual farms have remained small. The small sizes of farms were originally created by the land reform policies after the war, but they remained even after liberalization of the land market because of high transaction costs, including investment on infrastructure. Thus, in Japan, producers have not benefitted from economies of size in terms of their farmland. However, severe scarcity of farm land, which existed before the war, has been relaxed due to technological development rasing yields and due to the reduction of aggregate output.

Labor

The population of full-time and part-time farmers in Japan is 11 million, accounting for about 10 percent of Japan's population. The number of farmers and the number of farms decreased rapidly in the last several decades (Table 2.2.3). From 1960 to 1994, the population in farm households decreased by 35 percent, while the number of farms also decreased by 54 percent (Table 2.2.4). In addition, the tables show that the average number

Table 2.2.3 Population of Farm Households (Unit: thousands, percent in parentheses)

	Total	16-29 years old	30-39 years old	40-49 years old	50-59 years old	more than 60 years old
1960	22,622 (100)	7,293 (32.2)	4,359 (19.3)	3,428 (15.2)	3,218 (14.2)	4,218 (18.6)
1965	20,487 (100)	5,614 (27.4)	3,949 (19.3)	1,602 (7.8)	3,013 (14.7)	4,419 (21.6)
1970	19,460 (100)	5,815 (29.9)	3,171 (16.3)	2,848 (14.6)	2,891 (14.9)	4,427 (22.7)
1975	17,987 (100)	4,700 (26.1)	2,355 (13.1)	3,556 (19.8)	2,920 (16.2)	4,455 (24.8)
1980	17,083 (100)	3,911 (22.9)	2,466 (14.1)	2,836 (16.6)	3,296 (19.3)	4,573 (26.8)
1985	15,890 (100)	3053 (19.2)	2,637 (16.6)	2,193 (13.8)	3,167 (19.9)	4,841 (30.5)
1990	13,902 (100)	2,336 (16.8)	2,099 (15.1)	2,074 (14.9)	2,408 (17.3)	4,985 (35.9)
1994	10,516 (100)	1,078 (10.3)	1,452 (13.8)	1,702	1,635 (15.5)	4,033 (38.4)

Source: The Japan Ministry of Agriculture, Forestry and Fisheries, *Report on Movement in Agricultural Structure*
Note: People less than 16 years old are not included.

Table 2.2.4 Number of Farm Households (thousands)

	Total	Full-time	Part-time Type I	Part-time Type II
1960	6,057 (100)	2,078 (34.3)	2,036 (33.6)	1,942 (32.1)
1965	5,664 (100)	1,219 (21.5)	2,081 (36.7)	2,365 (41.8)
1970	5,260 (100)	798 (15.2)	1,566 (29.8)	2,895 (55.0)
1975	4,891 (100)	659 (13.5)	1,002 (20.5)	3,231 (66.1)
1980	4,614 (100)	580 (12.6)	829 (18.0)	3,205 (69.5)
1985	4,331 (100)	643 (14.8)	660 (15.2)	3,028 (69.9)
1990	2,936 (100)	460 (15.7)	478 (16.3)	1,998 (68.1)
1994	2,787 (100)	449 (16.1)	386 (13.9)	1,951 (70.0)

Note: Part-time type I: a part-time farmer farm household that earns the majority of the income in farming; Part-time Type II: a farm household which earns the majority of its income in non-farming employment.
Source: The Japan Ministry of Agriculture, Forestry and Fisheries, ***Report on Movement in Agricultural Structure***

of farmers per farming household slightly increased from 3.73 in 1960 to 3.77 in 1994. This is probably because proportion of part-time farmers increased.

The main reason for the decreasing population of farmers is migration from the agricultural sector to the industrial sector. From 1952 to 1980, those who moved from the agricultural sector totaled 4.3 million, accounting for 80 percent of the changes in the farm population.[19] The rest is attributed to a natural increase (*i.e.*, the number of the new borns minus that those who had died). The outflow of population occurred because of a desire to earn better incomes in the industrial sector. As Japanese industries developed in the mid-1950s, farmers sought better employment opportunities in urban areas. Thus, in addition to the moving of whole families, the moving of many young males was especially noted. Consequently, many old people and women remained in the rural areas. Traditionally in Japanese agriculture, male farm owners and their oldest sons remained on the farm as the successor of family farms, even if his brothers had to leave in order to earn money in urban areas and send it back to the farm. However, in recent years, because of increased migration of male farmers, the number of female farm owners increased and the number of young successors decreased. Table 2.2.3 shows that changes in the demographic patterns occurred as younger generations moved out of the rural areas and older generations did not. From 1960 to 1994, the number of farmers (*i.e.,* people in farm households) less than 30 years old decreased by 85 percent and those between 30 and 59 years old also decreased by 56 percent, while those more than 60 years old decreased by only 4 percent. This is due to the fact that

[19]Tsuchiya (1988) p. 15.

the younger generation expects greater benefits from seeking off-farm employment. Also, since the younger generation is more sensitive to differences in cultural and educational opportunities between rural areas and urban areas, reservation wages for agricultural activities are higher for younger generations.

The large scale migration to the urban areas resulted in a shortage of labor in the agricultural sector, especially for young and middle-aged people. In 1990, on average 11.3 percent of farms hired seasonal laborers for 36.7 man-days per farm. This accounted for only 2.9 percent of total labor hours in Japan. Use of hired labor decreased during the 1960s and remains very small (Table 2.2.5).

Table 2.2.5 Average Working Hours per Farm in Japan (hours per farm household)

Year	1960	1965	1970	1975	1980	1985	1990
Family	3,724	2,880	2,575	2,189	1,906	1,874	1,728
Hired labor	247	107	86	56	43	52	51
Total	3,971	2,987	2,661	2,245	1,949	1,926	1,779

Source: The Japan Ministry of Agriculture, Forestry and Fisheries, *Statistical Yearbook of Ministry of Agriculture, Forestry, and Fisheries.*

While some people quit farming and found jobs in the industrial sector, other farmers engaged in non-agricultural jobs, yet remained in the agricultural sector. Such part-time farming became possible as traffic systems were developed and manufacturing and service industries developed around rural areas. Consequently, fewer farmers moved into urban areas during slack seasons and engaged in temporary non-agricultural jobs. Table 2.2.6 shows the number of temporary workers away from home. Most of them engaged in farming in the rural areas and had seasonal jobs in urban areas. The number of temporary workers has decreased since the 1970s.

Table 2.2.6 Number of Temporary Workers Away From Home (thousands)

Year	1965	1970	1975	1980	1985	1990
Number of workers away from home	230.2	291.5	190.4	133.2	89.4	58.7

Source: The Japan Ministry of Agriculture, Forestry and Fisheries, ***Report on Movement in Agricultural Structure***

Eighty-two percent of the part-time farmers earned more income in other jobs (Table 2.2.4). The proportion of part-time farmers increased during the 1950s and 1960s. The number of part-time farmers relative to all farmers was 55 percent in 1938 and did not increase until 1950. However it increased rapidly in the 1950s and 1960s, and it rose to 84 percent in 1970.[20] This high ratio remains. In 1994, 84 percent of the total farmers were still part-time farmers.[21] A part-time farmer is able to shift working hours from farm production to non-farm employment without paying the large costs of moving to new areas and seeking a new job.

When labor is abundant, the marginal product of labor must be close to zero. Yet, Tsuchiya's (1988) study found that the marginal product of agricultural labor was, in general, significantly higher than zero in Japan. As the output level changes, the marginal product of

[20]Misawa (1970) and The Japan Ministry of Agriculture, Forestry and Fisheries, ***Agricultural Statistics Yearbook***.

[21]The numbers exclude self-sustaining farmers.

labor also changes. Very few studies on changes in marginal productivity of labor have been done in the past.[22] This issue, however, is useful in explaining the mechanism of technological change in agriculture.

Chemicals

"Chemical inputs" are fertilizers, pesticides, herbicides, insecticides, and other agricultural chemicals. Fertilizers include organic fertilizers (*i.e.*, manure) as well as inorganic (*i.e.*, chemical) fertilizers. Since this study deals with production for the last fifty years, chemical fertilizers are of main interest. Chemical fertilizers began to be used extensively in the 1950s. Compared with manure, chemical fertilizers are easily carried and applied; mixing is not required. Also, chemical fertilizers penetrate deeper into the soil than manure and therefore, more yield is expected.

Most chemical inputs are supplied by both domestic and foreign sources. The proportion of imported nitrogen (N), phosphorus (P), and potassium (K) in domestic consumption was, respectively, 30%, 18%, and 40% in 1991.[23] As demand for fertilizers increased, foreign chemical factories as well as domestic factories increase the supply. Therefore, the long-run supply of chemicals is elastic with respect to their prices.

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[22]In the study of sericultural production in Japan, Nghiep and Hayami (1979) found that traditional sericultural production without summer-fall rearing activity exhibited lower and more rapidly diminishing marginal productivity of labor than the later developed production with the activity.

[23]The values are calculated from *Poketto Hiryo Yoran (Fertilizer Statistics Abstract)* compiled by the Japan Ministry of Agriculture, Forestry and Fisheries, and *Nihon Boeki Geppo(Monthly Statistics of Japanese Trade)* compiled by the Japan Ministry of Finance.

Increases in the quantity demanded for fertilizers are attributed primarily to declining prices. Until the 1970s, the price of agricultural chemicals declined more than other input prices, though this has slowed during the 1970s (Table 2.2.7).

Table 2.2.7 Consumption of Major Fertilizers in Japan (1,000 tons)

	Nitrogen	Phosphorus	Potassium
1950	466	289	98
1955	567	385	382
1960	693	486	520
1965	769	574	601
1970	866	653	606
1975	833	583	571
1980	816	690	556
1985	952	741	645
1990	942	690	567
1993	929	728	521

Source: The Japan Ministry of Agriculture, Forestry and Fisheries, *Statistical Yearbook of Agriculture, Forestry, and Fisheries.*

Chemical demand has been closely related to improvement in crop variety. During the period from 1890 to 1910, when Japanese agricultural development accelerated, several new varieties of rice, such as Jinriki, Aikoku, and Kamenoo, were introduced. For two decades, the share of production of the new varieties in total output increased from nearly zero to 40 percent. As a result, the average yield of rice increased from 2.2 tons to 2.6 tons per hectare (Hayami 1973, p. 161). Consumption of fertilizers increased approximately four times during the same period.

Initially, these varieties were developed by large farmers and distributed through local agricultural organizations and a government extension system. In 1904, the Japanese government started scientific research on new varieties. Then, in 1926 the government organized a research institution for new varieties into a national research center, regional experimental stations, and prefectural stations. The new research and extension system originally started for wheat and later was expanded to rice and then other crops. This institution successfully developed several new varieties in the 1930s.

Combined with farm mechanization, technologies based on agricultural chemicals increased the yield of crops. Mechanization, using a large tractor, enabled deep tillage which led to more effective use of fertilizers. Cultivating crops in different seasons smoothed out seasonal labor requirements, and enabled efficient use of the labor force. This practice was made possible by improvement of farm facilities and infrastructures. In certain cases, early season rice cultivation reduced chances of crop damage and contributed to increased yield and stable production. For example, introduction of early-maturing varieties in the northern region of Japan reduced damage from cold weather. Early cultivation became possible through the introduction of the protected rice nursery (*i.e.*, bed for rice seedlings). This cultivation technique was adopted by 80 percent of the farmers in the northern region during the late 1960s. In the southern region of Japan, early cultivation also reduced damage from rice diseases.

Application of chemical inputs is characterized as both labor-saving and labor-using. Application of fertilizer often requires considerable amounts of labor. As a shortage of labor appeared after the 1960s, such labor-using technology was avoided. Also, as large-sized machinery began to be used, farmers preferred relatively short (dwarf) varieties, which are more suitable when using machinery. Thus, introduction of the new high-yielding varieties whose yield is sensitive to fertilizers was reduced.[24] Application of chemical inputs in making a protected rice nursery, spraying pesticides, and planting seedlings also require a large amount of labor. On the other hand, pesticides, herbicides, and insecticides are effective in reducing hours of work.

Thus, chemical inputs become substitutes or complements for other inputs by changing production technologies. Under given production practices, however, each chemical input has an effect on a specific role or function and it is effective for a specific amount per output. Productivity increases, in general, are generated not by a greater amount of chemical inputs but by technological changes, such as the introduction of a new variety that is responsive to fertilizers. Thus, chemical inputs are used within relatively narrow ranges, since the marginal productivity of the chemicals tends to diminish rapidly.

Capital

Capital inputs include machinery, equipment, facilities, infrastructure, and energy. Many of the tractors used in Japanese agriculture are small. Table 2.2.8 shows the average number of tractors per farm for all areas[25]. A pulling-type tractor is a small-sized tractor and a riding-type tractor is larger-sized. The number of pulling-tractors and riding-tractors with less than 15 horsepowers per farm was 0.77, accounting for 60 percent of the total number of tractors in Japan. Also, large-scale farms tend to own more large-size tractors. While only 5 percent

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[24]Kayou, pp.60-61.

[25]These number are underestimated, especially for smaller farms, since they do not include tractors owned by communities which are shared. In 1990, tractors owned by communities accounted for 3 percent of the total number of tractors in Japan.

of farms in all areas of Japan except Hokkaido have large tractors with more than 30 horsepowers, each farm in Hokkaido has more than one large tractor on average[26]. Thus, larger farms have large tractors which reduce the average cost of large-scale farming. Moreover, most power sprayers are also small in Japan. Riding power sprayers account for only 3.3 percent of the total number of sprayers.[27]

Table 2.2.8 Average Number of Tractors per Farm in 1992

	Pulling Tractor	Riding Tractor		
		0-15PS*	15-30PS	30PS and over
All areas except Hokkaido	0.63	0.14	0.47	0.05
0 - 0.5 ha.	0.59	0.17	0.19	0.01
0.5 - 1.0 ha.	0.65	0.18	0.40	0.01
1.0 - 2.0 ha.	0.65	0.11	0.65	0.04
2.0 ha.+	0.60	0.06	0.75	0.28
Hokkaido	0.23	0.02	0.26	1.40

*horse power
Sources: The Japan Ministry of Agriculture, Forestry and Fisheries, *Report on Movement in Agricultural Structure*

From an international perspective, Japanese farmers have many tractors. The number of tractors, regardless of size, was 2.12 million in Japan in 1990, compared with 4.75 million in

[26]Hokkaido is a northern island that has extraordinary large plains for Japan. The average area per farm in Hokkaido is 4.88 hectares for rice and 8.71 hectares for other field crops, while the average area per farm for all of Japan is 0.77 hectares and 0.53 hectares, respectively. Thus, Hokkaido is a good example of production in large-sized farms in Japan.

[27]Sources: The Japan Ministry of Agriculture, Forestry and Fisheries, *Survey of Statistics on Movement.*

the United States, 2.61 million in the former Soviet Union, and 1.47 million in France.[28] This suggests that mechanization in Japanese agriculture is not behind but has developed as small-scale mechanization or "mini-mechanization" takes place (Hayami and Ruttan, 1985).

Farm mechanization was induced by serious labor shortages beginning in the 1950s. As labor became a scarce resource, wages of farmers relative to machinery prices increased. Also, technological development in the manufacturing sector reduced prices of agricultural machinery. Thus, mechanization was accelerated by changes in relative factor prices. Another factor that promoted farm mechanization was improvement of agricultural land and rural roads during the last several decades. The irregular shapes of farms were arranged into rectangular shapes so that machinery could be more easily used. Development of farm roads in the rural areas also facilitated the introduction of machinery.

Small-sized machinery was first introduced in the mid-1950s. Table 2.2.9 shows that small-sized machines, such as tractors and power sprayers and power dusters, were popularized during the 1960s. In the 1970s, large machines, such as combines (auto-threshers), as well as rice planting machines, began to be used extensively. Due to mechanization, farmers' working hours were rapidly reduced. As a result, productivity of labor in rice production increased by 6.9 percent a year during 1955-65 and 5.7 percent during 1965-85.[29] However, very large-sized machinery like those used in the United States, was not widely adopted in Japan, since most farms were not large enough to use this type of machinery.

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[28]FAO, *Production Yearbook*

[29]Y. Hayami and associates (1974) and Yamada (1984)

While using large-sized machinery would increase yield because of deeper tillage, small-sized machinery saves labor but does not raise the yield much.[30] Thus, mechanization in Japan promoted substitution of machinery for labor rather than increases in yield.

Table 2.2.9 The Number of Major Machinery Items Owned by Japanese Farmers (unit: 1,000)

	Tractors	Power sprayers, power dusters	Rice power planters	Combines, auto threshers
1960	278	406	0	0
1965	1,919	850	0	0
1970	3,448	2,170	33	45
1975	4,014	3,060	470	525
1980	4,223	3,364	1,746	916
1985	4,387	n. a.*	1,993	1,150
1990	3,731	n. a.	1,904	1,179

Source: The Japan Ministry of Agriculture, Forestry and Fisheries, *Annual Sample Survey of Agriculture*
*data not available.

2.3 Changes in Output and Factor Use

The previous section discussed characteristics of inputs in Japanese agriculture and showed that the inputs may take various adjustment paths. Changes in inputs in response to a change in output cannot be assumed the same for all inputs, and the adjustment paths cannot be determined *a priori*. Adjustment of some factors may be more rigid in the short run, while others may be adjusted flexibly.

Some economists have argued that some factors are rigid or fixed due to a problem of

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[30]Tsuchiya (1988) p. 217; Inamoto (1987) p. 117

disequilibrium in agricultural production, based on a hypothesis that agricultural production is not at the optimal level.[31] However, Tweeten (1989) suggested that there is no supporting evidence that this disequilibrium persists; and in the long run, the factor market will be adjusted toward the equilibrium level. Also, he found that costs of input transfer are not large enough to prevent adjustment. Thus, the problem is not a permanent disequilibrium of the market, but a temporary disequilibrium and slow adjustment. Also, Chambers and Vasavada (1983) argued that producers make decisions according to their expected input prices, however if the prices are not realized, the inputs are in short-run disequilibrium[32].

Rigidity in factor adjustment is explained by delay or by characteristics of the production technology (*i.e.*, nonhomotheticity). The short-run disequilibrium model can be used to deal with the former problem. In terms of the latter problem, if production is highly non-homothetic, adjustment of some factors may appear rigid.

As more input is used, the productivity of an input in general increases at a diminishing rate ceteris paribus. A profit maximizing firm uses inputs so that the ratio of the marginal products of the inputs equal the ratio of factor prices. Under a given factor price ratio, a

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[31]Galbraith and Black (1938) argued that since agricultural production requires an expensive and lumpy fixed factor, producers are not able to shift fixed factors in the short run. According to Johnson (1956), this is caused by divergence between acquisition costs and salvage value of inputs. Also, Brewster (1961) attributed fixity in labor to family farm workers' low reservation wage. Bischoff (1971) proposed the so called "putty-clay technology" hypothesis--that is, producers are free to choose any input combination, but they are not allowed to change the input combination after they start production, therefore, therefore leading to irreversibility.

[32]Chambers and Vasavada also argued that high costs of adjustment may form the putty-clay technology (*ex post* asset fixity) or restrict choices of inputs within a certain range as a farmer's organization cannot be flexibly adjusted to its environment,(*ex ante* asset fixity).

factor with a slowly diminishing marginal product must be used more in order to make its marginal product equal to the others.

Graphically, nonhomothetic production shows a nonlinear expansion path[33]. Figure 2.1 illustrates a case of production with two factors (x_A, x_B). In Figure 2.1(a), as the output increases from q^0 to q' and q'', the bundle of inputs changes from (x_A^0 x_B^0) to (x_A' x_B') and (x_A'' x_B''). Thus, the rate of change in the input x_A is smaller than the rate of change in the input x_B for a fixed factor price ratio. Figure 2.1(b) shows the relationship between the input x_A and the output q under given levels of the input x_B. In Figure 2.1(a) and Figure 2.1(b), if a level of the input x_B were fixed at x_B^0, then, as the output increases from q^0 to q', the input x_A would increase from x_A^0 to x_A^1. If a level of the input x_B is constant, the production function exhibits diminishing marginal product, indicated by the line x_B^0. As the output increases from q^0 to q', the input x_B will shift from x_B^0 to x_B' and the input x_A will increase from x_A^0 to x_A'. Similarly, as q increases to q'', x_A will be at x_A'' since x_B again shifts to x_B''. Thus, the rate of an increase in input x_A is smaller than the rate of change in the output. In other words, the average level of the input per unit output declines as output increases. Figure 2.1 (c) shows that the rate of an increase in the input x_B is greater than the rate of increase in output.

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[33]The expansion path is defined as the locus of the chosen input levels at a constant ratio of factor prices as output.

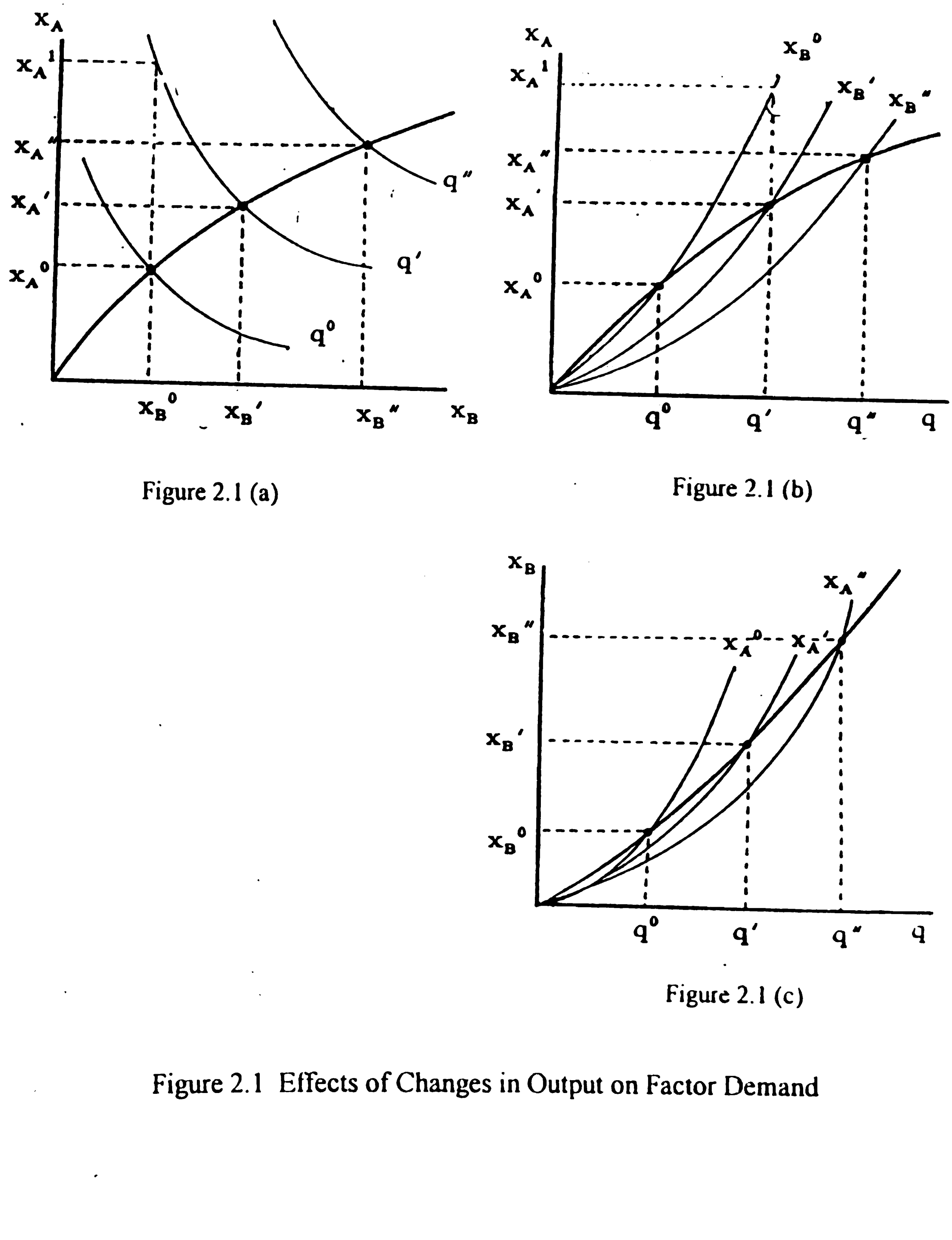

Figure 2.1 Effects of Changes in Output on Factor Demand

Thus, a multi-factor production is in general nonhomothetic since factor adjustment process is determined by characteristics of marginal product in terms of each factor. As discussed in the previous section, various factor adjustment process and factor substitution and complementarity effects are involved in Japanese agriculture. Therefore, a model for the factor adjustment analysis should be specified to be as flexible as possible, rather than a functional form is determined *a priori*.

2.4 Summary

This chapter provides broad background information for the study. Since the motivation of this study includes how the coming import liberalization policies might affect the rural sector by changing the demand for production factors, this chapter deals mainly with Japanese trade policy and productive factors of agriculture

Persistent protectionism of Japanese trade is explained by perceived benefits and costs from the import protection policies. The perceived benefits include national food security, food safety, supporting farmers' incomes and employment opportunities, and preserving the rural landscape and water resources. The costs include higher food prices, as well as environmental damage by farming, such as contamination of water resources by agricultural chemicals.

As import liberalization changes employment opportunities and chemical contamination, the characteristics of productive factors, such as labor and chemicals, are important to understand the effects of policy.

As has been noted in this chapter, labor has been a scarce resource in Japanese agriculture. Therefore, there may be little potential unemployment in the rural areas due to import liberalization. It is expected that a less labor-intensive production structure will be developed in the future as output declines due to trade liberalization. Also, the number of part-time farmers has been increasing due to the development of regional economies, and the traffic system around rural areas. The latter has enhanced mobility of labor between the farming sector and the off-farming sector. Rigidity in labor adjustment has been diminishing over time.

Scarcity of land, which used to be a severe problem in Japan, has been relaxed as land-saving technology developed and the agricultural sector shrank. Since production costs per hectare are higher for small-scale farms, the proportion of small-scale farms will decline as the agricultural sector contracts. Because larger farms use more chemicals and machinery in farming, there are serious concerns about contamination of water systems caused by agricultural chemicals, especially those used in paddy rice production, as well as concerns about pesticide residues on the harvested products. Thus, excessive use of the chemicals might cause further environmental problems.

In terms of adjustment of factors, some inputs, such as land, machinery, infrastructures and facilities, are difficult to adjust to their optimal levels in the short-run. Therefore, a method which incorporates an intertemporal adjustment process is required for this study. In the next chapter, modeling issues with such an adjustment process will be discussed.

CHAPTER 3

A DYNAMIC COST FUNCTION MODEL

This chapter discusses properties of functional forms and problems of the model selection. First, we characterize the cost function using duality theory. Next, the properties of functional forms and dynamic models are discussed. Then, we derive the dynamic flexible model used here, as well as discuss estimation methods for factor demand elasticities.

3.1 Duality and Cost Function

Duality Theory

A cost function has the same information about the production technology as a production function. In other words, properties of a production function are dual to properties of a cost function. This is the principle of duality. Duality theory was first proposed by Hotelling (1932) but the fundamental theory was developed by Shephard (1953). In the 1970s, it was further developed by Fuss and McFadden (1978), Diewert (1971, 1973, 1974), Berndt and Christensen (1973), and Lau (1976).

Duality functions describe results of optimizing responses to prices under certain constraints, rather than global responses to input and output quantities as in the corresponding production function (Young *et al.* 1985). While a production function describes global output response to possible combinations of the inputs, a cost function describes the optimal or minimum cost of producing a certain level of the output under given input prices and the production technology. Thus, whereas production functions are primal functions which contain all of the information about the production technology, the cost function, as a dual function, contains information about the behavior at the optimum (*i.e.*, cost minimization) as well as the technology. This is an advantage of using a dual function because the homogeneity, monotonicity, and curvature properties in production are already imposed in the cost function. Therefore, one does not have to assume these conditions to obtain the optimizing input mix. Instead, these conditions may be tested. One does not have to solve the maximization problems: they are already solved implicitly in the dual function.

Also, price variables used in a cost function are generally regarded as exogenous variables in terms of a choice problem of the firm, while factor levels used in a production function are usually decision variables for the firm (Binswanger, 1974b). This makes a cost function useful in empirical studies because it avoids simultaneity problems. Moreover, according to McLean-Meyinsse and Okunade (1988), input prices are less likely to have multicollinearity, compared with input quantities, so a cost function mitigates multicollinearity problems among the independent variables.

Properties of Cost Functions

A set of inputs X yielding a given level of output q, is represented by a classical production function $q = f(X)$ where f is increasing in inputs, strictly quasi-concave, continuous for all nonnegative input bundles, equals zero at zero inputs, and is unbounded when all inputs are unbounded. A cost function is derived from this production function by solving

$$C(W, q) = \min [\, WX \mid f(X) \geq q \,]$$

where W is the vector of input prices. If the cost function is concave, nondecreasing, positive linear homogeneous, and continuously differentiable in input prices for each level of output, it is called a "quasi cost function." Also, the quasi cost function is called a classical cost function if it is continuous and increasing in output, equals zero at the zero output level, and is unbounded for unbounded output (McFadden 1978)

Properties of a classical cost function can be described in detail. Obviously the classical cost function is nondecreasing with respect to input prices. If every input price of the vector W′ is greater than or equal to the corresponding prices of the vector W, then the cost of using W′ is greater than or equal to the cost of using W to produce the same level of the output. Also, the cost function is homogeneous of degree one in the input prices. If all input prices increase by k times, then the cost increases by k times. Thus, the cost function can be expressed

$$C(kW, q) = k\,C(W, q).$$

for any k. The cost function is concave in input prices W, because if the price of an input increases, then costs increase at a decreasing rate.

If there is no substitution between the inputs, we have the case of a passive cost function. The passive cost function is expressed as

$$C = w_1 x_1^* + \Sigma_{i \neq 1} w_i^* x_i^*,$$

where w^* and x^* are the previous prices and levels of the input, which are held constant even after the input price w_1 changes. However, if the price of an input increases, the cost minimizing firm shifts from the relatively expensive input to other inputs. Therefore, the minimized cost $C(W^*, q)$ is on or below passive cost. Mathematically, concavity means that the matrix of second derivatives is negative semidefinite at every point. In terms of two input price bundles W and W′, concavity is written as

$$C(kW + (1 - k)W', q) \geq kC(W, q) + (1 - k)C(W', q) \quad \text{for } 0 < k < 1.$$

3.2 Functional Form

Choice of Functional Form

A functional form is a model that approximates an unobservable economic relationship. A choice of a functional form should be based on maintained hypotheses for the study. The maintained hypothesis is not a hypothesis to be tested as part of the analysis but a hypothesis to be assumed true for the research process (Fuss *et al.* 1978). For example, if a maintained hypothesis is that the elasticity of substitution is unity for any input combination, the Cobb-Douglas production function may be an appropriate model, otherwise, a more flexible model, such as the CES or translog function, should be used. Examples of maintained hypotheses often used in production analyses are concavity, homogeneity, and homotheticity of functions, and profit maximization.

Criteria in choosing a functional form include theoretical consistency, applicability domain, flexibility, and computation facility (Lau, 1986). First, theoretical consistency is the ability of the functional form to satisfy the theoretical properties required of the particular economic relationship. For example, a cost function is homogeneous of degree one, concave, and non-decreasing in input prices. Thus, an algebraic functional form should be chosen to satisfy these requirements, at least at a neighborhood of the range of data used in the estimation.

Second, all values of variables must be used in the functional form within the domain where the functional form satisfies all theoretical requirements in economics. In a cost function, for example, the prices of inputs, the outputs, and the costs must be non-negative; the first derivatives of the cost function must be also non-negative, and the Hessian matrix of the second derivatives must be negative semidefinite.

Third, flexibility is an important factor in choosing a functional form. Flexibility is defined as the ability of the algebraic functional form to approximate arbitrary but theoretically consistent behavior through an appropriate choice of the parameters. There are two kinds of flexibility: local flexibility (Diewert flexibility) and global flexibility (Sobolev flexibility). According to Fuss, McFadden, and Mundlak (1978), local flexibility implies a perfect approximation to the true function and its first two derivatives at a particular point. On the other hand, global flexibility approximates the true function in any possible range. Thus, the true function and its first and second derivatives are perfectly approximated.

Fourth, computational facility is another criterion in choosing a functional form. For example, linearity in parameters or linearity in parameter restrictions is an important factor to enable parameters to be estimated at reasonable costs of computation. Also, the number of parameters in the functional form should be the minimum number required to achieve the desired degree of flexibility. In addition, Griffin (1987) argues that the functional form should be selected according to general conformity of the function to given data. For example, a data set may be fit better with a logarithmic model than a linear model. That is, among functional forms that have similar degrees of flexibility, one should choose a functional form that fits better than the others.

Overall, Lau (1986) argues that satisfying all of these criteria simultaneously is, in general, impossible. Therefore, he suggested flexibility be maintained as much as possible, since inflexibility restricts the sensitivity of the parameter estimates to the data and limits *a priori* what the data are allowed to tell the econometrician. Also, he does not recommend sacrificing computational facility since nonlinear-in-parameters models are more likely to fail in statistical estimation than linear-in-parameter models, and statistical theory of non-linear estimation is less developed than linear estimation.

As Griffin *et al* (1987) stated, selection of a functional form should be based on maintained hypotheses and statistical processes of parameter estimation. With few maintained hypotheses, more flexible forms may be appropriate. If the maintained hypotheses implied by a functional form are acceptable, the function is appropriate. Also, a choice of functional form depends on availability and properties of data used for the estimation. With a greater number of observations a more flexible form is allowed because of greater degrees of freedom. In the rest of this section, we discuss the properties of various functional forms.

Various Functional Forms

The well-known approximating functional forms, Cobb-Douglas, CES, the generalized Leontief, and translog functions, are forms that are linear in parameters. Let x be a vector of independent variables. Then, the first order Taylor's series evaluated at x^* is given by $f(x^*) + \Sigma_i f_i(x^*)(x_i - x_i^*)$ and the second order Taylor's series adds a second order term, $1/2\Sigma_i\Sigma_j f_{ij}(x^*)(x_i - x_i^*)^2$ to this for $i,j= 1, \cdots, n$, where the subscript on f shows its differentiation with respect to the corresponding x.

The Cobb-Douglas production function is a first order Taylor's expansion of log quantity in powers of $\ln x_i$. In the case of n inputs and one output, the Cobb Douglas production function is

$$q = \alpha \prod_{i=1}^{n} x_i^{\beta_i} \tag{1}$$

where q is the output level, x_i is the quantity of the i-th input for i= 1,···, n, α and β_i (i = 1,···,n) are parameters. A Cobb-Douglas cost function dual to this production function is expressed as

$$C = \alpha^* \prod_{i=1}^{n} w_i^{\beta_i^*} q^{\beta_q^*} \tag{2}$$

where C is the total cost of production, w_i is the price of the i-th input for i = 1, ··· , n, and the parameter $\alpha^* = 1 / \alpha$. The Cobb-Douglas function allows free assignment of the output level, returns to scale, and distributive shares. Also, the Cobb-Douglas function is convenient for estimation since it is linear in logs. However, Arrow *et al* (1961) questioned the restriction of this function that all elasticities of factor substitution are equal to one. Thus, economists have attempted to develop new models that impose less restrictions on factor substitution.

The constant elasticity of substitution (CES) function corrects the problem of unit elasticity of substitution in the Cobb-Douglas. It takes any constant value for the elasticity of substitution. This function is a first-order Taylor's expansion of y^ρ in powers x_i^ρ.

$$q = [\beta_0 + \textstyle\sum_{i=1}^{n} \beta_i x_i^{-\rho}]^{-1/\rho} \tag{3}$$

and the cost function dual to this production function is

$$C = [\beta_0^* + \textstyle\sum_{i=1}^{n} \beta_i^* w_i^{-\rho} + \beta_q^* q^{-\rho}]^{-1/\rho} \tag{4}$$

where $\beta^*_i = 1 / \beta_i^\rho$ for i = 1,···, n, and ρ = 1-1/σ for the elasticity of substitution σ. In the

CES model, however, partial elasticities of substitution are equal for all input combinations.

Sato (1967) developed the nested CES function, which relaxes the restriction that partial elasticities of substitution are equal across input combinations. For example, assuming four inputs such that inputs x_1 is a substitute factor of x_2 and x_3 is a substitute of x_4, a two-level CES production function is expressed as follows.

$$\begin{aligned} z_A &= [\beta_A x_1^{-\rho_A} + (1-\beta_A) x_2^{-\rho_A}]^{-1/\rho_A} \\ z_B &= [\beta_B x_3^{-\rho_B} + (1-\beta_B) x_4^{-\rho_B}]^{-1/\rho_B} \\ q &= [\gamma x_3^{-\rho} + (1-\gamma) x_4^{-\rho}]^{-1/\rho} \end{aligned} \qquad (5)$$

Let s_1 be the factor share of the sum of input 1 and input 2 and s_2 be the factor share of inputs 3 and 4. Then, the Allen partial elasticities of substitution are

$$\begin{aligned} \sigma_{13} &= \sigma_{14} = \sigma_{23} = \sigma_{24} = \sigma \\ \sigma_{12} &= \sigma + [1/(\rho_1 + 1) - \sigma]/s_1 \\ \sigma_{34} &= \sigma + [1/(\rho_2 + 1) - \sigma]/s_2 \end{aligned} \qquad (6)$$

Thus, the elasticities of substitution are constant for some of factors. The nested CES is not extensively used in empirical work, however, since as the number of factors increases, estimation of the function becomes very complicated.[34]

Functional forms that are more flexible than the Cobb-Douglas and the CES functions include the generalized Leontief function, the generalized Cobb-Douglas function, the generalized quadratic function, and the transcendental-logarithmic (translog) function. These models are second-order Taylor's approximations of arbitrary functions. These functional forms impose no restrictions on elasticities of substitution between inputs. Also, returns to

[34]Fuss *el al.* (1978), p. 242.

scale are allowed to vary with the level of output.

The generalized Leontief function introduced by Diewert (1971) is a Taylor's expansion of q in powers of $x^{1/2}$.

$$q = \beta_0 + \sum_{i=1}^{n} \beta_i x_i^{1/2} + \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} x_i^{1/2} x_j^{1/2} \tag{7}$$

Also, the generalized Cobb-Douglas function production is expressed as

$$\ln q = \beta_0 + \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} \ln[(x_i + x_j)/2] \tag{8}$$

The generalized quadratic function is as follows

$$q = [\sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} x_i^{\alpha\gamma} x_j^{\alpha(1-\gamma)}]^{v/\alpha} \tag{9}$$

All of the generalized Leontief, generalized quadratic, and generalized Cobb-Douglas production functions are homothetic.[35] None of these assume concavity. The generalized Leontief function is concave when all β_{ij} in the above equation are non-negative; the generalized Cobb-Douglas function is not concave in general; and the generalized quadratic function is concave if all $\beta_{ij} \geq 0$, $0 \leq \gamma \leq 1$, $\alpha \leq 1$, and $v \leq 1$ (Griffin *et al*, 1987).

The translog production function was developed by Christensen *el al.*(1971) and can be represented

$$\ln q = \beta_0 + \sum_{i=1}^{n} \beta_i \ln x_i + 1/2 \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} \ln x_i \ln x_j \tag{10}$$

This function does not assume homotheticity, concavity, nor constant elasticity of

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[35]A function is homothetic if it can be represented as a monotonic transformation of a function that is homogeneous of degree one. A function f is homogeneous degree one if it satisfies $f(kx_1, kx_2, \cdots, kx_n) = k f(x_1, x_2, \cdots, x_n)$, for an arbitrary constant k.

substitution, unless restrictions are imposed on parameters. While the flexibility of translog function is greater than other flexible functions described above, parsimony of parameters is less. In a case of production with n inputs, the number of parameters in this translog production function will be $\frac{1}{2}(n^2+3n+3)$, while the generalized Leontief is $\frac{1}{2}(n^2+n)$; generalized Cobb-Douglas is $\frac{1}{2}(n^2+n+2)$; and generalized quadratic function is n^2+3. The properties of the translog cost function are discussed in detail below.

Translog Cost Function

As stated above, the translog cost function model is derived as a second-order Taylor's approximation. The general form of a Taylor's expansion for the function $f(x)$ around $x = a$ is

$$f(x) = f(a) + 1/1!\, f_1(a)(x - a) + 1/2!\, f_2(a)\,(x - a)^2 + \cdots + 1/(n-1)!\, f_{n-1}(x - a)^{n-1} + 1/n!\, f_n(a + \theta(x-a))\,(x-1)^n$$

Since the last term approaches zero as n goes to the infinity, this equation can be rewritten as an infinite series:

$$f(x) = f(a) + 1/1!\, f_1(a)(x - a) + 1/2!\, f_2(a)\,(x - a)^2 + \cdots + 1/n!\, f_n(x - a)^n + \cdots$$

For the logarithmic form of the cost function: $\ln C = \ln G(\ln w_1, \ln w_2, \cdots, \ln w_n, \ln q, t)$ where w_i is i-th input, q is output, and t is the time trend, the Taylor's expansion with respect to $\ln C$, $\ln w_i$, $\ln q$, and t around the points of $\ln w_i=0$, $\ln q=0$, $t=0$ is w

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$$\begin{aligned}\ln C &= \ln G(1,1,\cdots,1) + \sum_{i=1}^{n} \frac{\partial \ln G}{\partial \ln w_i}\ln w_i + \frac{\partial \ln G}{\partial \ln q}\ln q + \frac{\partial \ln G}{\partial t}t \\ &+ \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \frac{\partial^2 \ln G}{\partial \ln w_i \partial \ln w_j}\ln w_i \ln w_j + \frac{1}{2}\sum_{i=1}^{n} \frac{\partial^2 \ln G}{\partial \ln w_i \partial \ln q}\ln w_i \ln q + \frac{1}{2}\sum_{i=1}^{n} \frac{\partial^2 \ln G}{\partial \ln w_i \cdot \partial t}\ln w_i \cdot t \\ &+ \frac{1}{2}\frac{\partial^2 \ln G}{\partial \ln q \cdot \partial t}\ln q \cdot t + \frac{1}{2}\frac{\partial^2 \ln G}{\partial q^2}\ln q^2 + \frac{1}{2}\frac{\partial^2 \ln G}{\partial t^2}t^2 + R(\ln w_1,\cdots,\ln w_n, \ln q, t)\end{aligned} \quad \textbf{(11)}$$

where R is the remainder. Assuming $\lim_{n\to\infty} R=0$, and $\partial \ln G/\partial \ln w_i = \beta_i$, $\partial \ln G/\partial \ln q = \beta_q$, $\partial \ln G/\partial \ln t = \beta_t$, $\partial^2 \ln G/(\partial \ln w_i \partial \ln w_j) = \beta_{ij}$, $\partial^2 \ln G/(\partial \ln w_i \partial \ln q) = \beta_{iq}$, $\partial^2 \ln G/(\partial \ln w_i \partial t) = \beta_{it}$, $\partial^2 \ln G/(\partial \ln q)^2 = \beta_{qq}$, $\partial^2 \ln G/\partial t^2 = \beta_{tt}$, the equation **(11)** will be the translog cost function.

Also, the Translog function is regarded as a general form of Cobb-Douglas functional form. Imposing the restriction $\alpha_{ij} = 0$, the translog function will be a Cobb-Douglas function in the above equation.

In order to make the translog function consistent with economic theory, it must satisfy several restrictions. The first restriction is symmetry. In the translog function above, $\beta_{ij} = \beta_{ji}$ for $i, j = 1,\cdots n$, $i \neq j$. It is explained mathematically such that

$$\beta_{ij} = \frac{\partial \ln G}{\partial \ln w_i \partial \ln w_j} = \frac{\partial \ln G}{\partial \ln w_j \partial \ln w_i} = \beta_{ji} \quad \textbf{(12)}$$

The second restriction is linear homogeneity of degree 1 in factor prices. If all factor prices increase k times, then the cost has to increase k times as well. Homogeneity implies

$$\sum_{i=1}^{n} \beta_i = 1, \quad \sum_{i=1}^{n} \beta_{ij} = 0, \quad \sum_{j=1}^{n} \beta_{ij} = 0 \quad \textbf{(13)}$$

for all i and j. The restrictions of symmetry and homotheticity may be added in a model to be estimated or they could be tested later. Third, since the cost function must be concave in factor prices, $\partial^2 C/(\partial w_i \partial w_j)$ has to be negative semidefinite. Also, this condition implies the matrix of the Allen's partial elasticities of substitution is also negative semidefinite (Binswanger 1974b). Fourth, monotonicity requires that the function be increasing as factor prices increase. Although it is desirable that this condition holds for any arbitrary values in the independent variables, in the translog cost function the condition cannot be mathematically imposed in the functional form. Thus, a local condition, instead of a global condition, is tested within the range of data.

$$\partial \ln C/\partial \ln w_i = \beta_i + \Sigma_j \beta_{ij} \ln w_j + \beta_{iq} \ln q + \beta_{it} t \geq 0$$

$$\partial \ln C/\partial \ln q = \beta_q + \Sigma_j \beta_{ij} \ln w_j + \beta_{iq} \ln q + \beta_{it} t \geq 0$$

$$\partial \ln C/\partial t = \beta_t + \Sigma_j \beta_{ij} \ln w_j + \beta_{iq} \ln q + \beta_{it} t \geq 0$$

Among these, the first equation should be generally true, since it is equal to the cost share of the i-th factor (S_i).

More Flexible Forms

There are some functions that are more flexible than the translog. For example, the generalized Box-Cox form

$$\begin{aligned} q(\theta) &= \alpha_0 + \alpha_i x_i(\lambda) + \textstyle\sum_{i=1}^{n} \sum_{j=1}^{n} \alpha_{ij} x_i(\lambda) x_j(\lambda) \\ \text{where} \quad q(\theta) &= (q^{2\theta} - 1) \\ \text{and} \quad x_i(\lambda) &= (x_i^{-\lambda} - 1)/\lambda \end{aligned} \tag{14}$$

This functional form is a nested form of many other forms. For example, it is linear in logs when $\theta = ½$, and $\lambda = 0$, Cobb-Douglas when $\theta = \lambda = 0$, $\Sigma_{i=1}\alpha_i = 1$, and all $\alpha_{ij} = 0$, CES when $v\theta = \lambda$, $\lambda\alpha_i = 2\alpha_{ii}$, and $\alpha_{ij} = 0$, translog when $\theta = \lambda = 0$, and generalized Leontief when $\theta = \lambda = ½$.

Model Selection in This Study

So far, we have discussed criteria in selection of a functional form and properties of major functional forms. The main objective of this study is to estimate output elasticities of factor demand, as well as elasticities of substitution, using a dynamic econometric model. Thus, the selected models have to be flexible in terms of economic properties and relatively unrestricted in the parameters. Thus, the models that assume constant elasticities of substitution should be excluded. Although there are many studies using the Cobb-Douglas function in Japanese agriculture, there is no reason to assume that elasticities of factor substitution are one. The hypotheses of constant elasticity of substitution and homotheticity in the production process have been rejected in some previous studies (*e.g.*, Kuroda, 1987). As discussed above, the translog function does not have constant elasticity of substitution and homotheticity as maintained hypotheses. Yet, even though flexibility is desirable, more flexible models, such as the generalized Box-Cox model require an extremely large number of parameters to be estimated. Thus, the translog appears to be the best choice for this study.

3.3 Dynamic Models

Various Dynamic Forms

Early production and cost function models implicitly assumed production factors were in long-run equilibrium, that is, all factors are assumed to be adjusted immediately to the cost minimizing levels. The assumption of short-run equilibrium is, however, unrealistic in many cases, because adjustment is often slow and disequilibrium may occur in the short run. A classical means of incorporating dynamic structures in the factor demand analysis is the partial adjustment model (*e.g.*, Lucas 1967, Treadway 1969 and 1974, Mortensen 1973). This model is rationalized in the sense that it contains mechanisms consistent with dynamic optimization behavior. A limitation of this model is that the rate of the adjustment is constant in all factors, and therefore the short-run elasticity and the long-run elasticity are always proportional with a constant ratio (Taylor and Monson 1985). Another model that overcomes this problem is a static model with *ad hoc* dynamic terms representing adjustment costs or expectations (*e.g.*, Jorgenson 1965). Even though this model contains dynamic elements, another *ad hoc* functional form, such as a quadratic cost of adjustment, must be assumed. Dynamic duality models of factor demand are developed by McLaren and Cooper (1980) and Epstein (1981). The mechanism for this model is intertemporal optimization of a value function using the Hamilton-Jacobi-Bellman equation. This is consistent with the theory of adjustment cost (Epstein 1981), however, using this model, one must accept assumptions that the real discount rate is constant and that the producer uses production factors so as to maximize the net present value for the future production process.

Dynamic econometric models, such as the distributed lag model and the ARMAX model, explicitly incorporate intertemporal relations between the independent variables and the dependent variables. These models are useful for empirical research where the mechanism of the dynamic structure is unknown.

The dynamic econometric model with ad hoc dynamic terms is adequate for analysis of Japanese agriculture, since there is no clear consensus about the mechanism of the dynamic adjustment process. Slow adjustment of factors is due to either high adjustment costs in the short run, time lags of market information transmitted to farmers, time lags of obtaining or disposing of factors (*e.g.*, infrastructures), the dynamics of farmer's expectation formation.

Dynamic Econometric models

This section briefly reviews dynamic econometric models with lag structures. Suppose the static relationship between $q(t)$ and $x(t)$ is expressed such as

$$q(t) = \alpha + \beta x(t) + \epsilon(t) \tag{15}$$

where β is the vector of coefficients on the independent variables $x(t)$ and $\epsilon(t)$ is a disturbance. Distributed lag models include finite lag models and geometric lag models. The model with a p-th order lag is

$$q(t) = \alpha + \sum_{i=0}^{p} \beta_i x(t-i) + \epsilon(t) \tag{16}$$

In this equation, β_0 is the short-run multiplier (the impact multiplier) and $\Sigma_{i=0}\beta_i$ is the long-run multiplier (equilibrium multiplier). In practice, this model has several problems: It contains so many parameters that degrees of freedom are often constrained. Also, the model may have a severe multicollinearity problem. Thus, Almon (1965) proposed a restricted distributed lag model with polynomial distribution of lagged coefficients. The polynomial distributed lag model effectively reduces the number of parameters, although it sacrifices some flexibility in the lag structure. In the finite distributed lag models, an appropriate length of the lag must be specified; however, it is often unknown.

The geometric lag model introduced by Koyck (1954) takes an infinite order of distributed lags as follows:

$$q(t) = \alpha + \beta \sum_{i=0}^{\infty} (1-\lambda)\, \lambda^i\, x(t-i) + u(t) \tag{17}$$

where $u(t)$ is the possibly autocorrelated error term. This model may be translated as an adaptive expectation model or partial adjustment model, depending on the assumption in the study. Under the assumption of adaptive expectation, $u(t)=\epsilon(t)-\rho\epsilon(t-1)$, where ρ is a parameter on the lagged error. In the adaptive expectation model, the current expectation $x^*(t)$ is formed as an average of current observations $x(t)$ and the previous expectation $x^*(t-1)$ with the weight λ: $x^*(t)=(1-\lambda)x(t)+\lambda x^*(t-1)$ or $x^*(t)=(1-\lambda)/(1-\lambda L)x(t)$, where L is a lag operator. Substituting this into an expectation model $q(t)=\alpha+\beta x^*(t)+\epsilon(t)$ will give and autoregressive form

$$(1-\lambda L)\, q(t) = (1-\lambda)\alpha + \beta\,(1-\lambda)\, x(t) + (1-\lambda L)\epsilon(t) \tag{18}$$

On the other hand, in terms of the partial adjustment model $q^*(t)=\alpha+\beta x(t)+\epsilon(t)$, the current level of $q(t)$ is a weighted average of the optimal level $q^*(t)$ and the previous level $q(t-1)$, thus, $q(t)=(1-\lambda)q^*(t)+\lambda q(t-1)$. For $0<\lambda<1$, the current level is adjusted towards its optimal level but it is also affected by the previous level. Another representation of this is $\Delta q(t)=(1-\lambda)[q^*(t)-q(t-1)]$, so that the current adjustment is made as a certain proportion of the previous error of adjustment to the optimal level. Since $q^*(t)=[(1-\lambda L)/(1-\lambda)]q(t)$, $q^*(t)=\alpha+\beta x(t)+\epsilon(t)$ is equivalent to

$$(1 - \lambda L)\, q(t) \;=\; (1-\lambda)\alpha \;+\; \beta(1-\lambda)\, x(t) \;+\; (1-\lambda)\, \epsilon(t) \qquad \textbf{(19)}$$

The major limitation of geometric lag models is that they take given shapes of lag patterns. The lag weights, however, might not be consistent with the data. Jorgenson (1966) proposed more general lag model, called the rational lag model or the autoregressive distributed lag (ARDL) model

$$q(t) \;=\; \alpha + \frac{\Gamma(L)}{\Phi(L)}\, x(t) \;+\; \epsilon(t) \qquad \textbf{(20)}$$

where $\Gamma(L) = \sum_{i=0}^{q} \Gamma_i L^{i}$, and $\Phi(L) = \sum_{i=0}^{p} \Phi_i L^{i}$. Various patterns of lag structures could be produced by the composite lag term $[\Gamma(L)/\Phi(L)]$. The autoregressive form of this equation is

$$\Phi(L)\, q(t) \;=\; \Gamma(L)\, x(t) \;+\; \Phi(L)\, \epsilon(t) \qquad \textbf{(21)}$$

Thus, the ARDL model has a restriction that the lag structure of $q(t)$ is just the same as those of the moving average term of the disturbance $\epsilon(t)$. A further general form relaxing this restriction is

$$\Phi(L)\, q(t) \;=\; \Gamma(L)\, x(t) \;+\; \theta(L)\, \epsilon(t) \qquad \textbf{(22)}$$

where $\theta(L)=\sum_{i=0}^{r}\theta_i L^i$. This is a general ARMAX model.[36] Although an advantage of ARMAX is its general and flexible characteristics, the number of the parameters may become too large for small size of samples. Then, by assuming $\theta(L) = I$, it may be transformed into a model called the ARX model:

$$\Phi^*(L)\,q(t) \;=\; \Gamma^*(L)\,x(t) \;+\; \epsilon(t) \tag{22}$$

The ARX model saves degrees of freedom, while keeping the flexible properties of the ARMAX model to a large extent.

The Flexible Model

This section develops a dynamic model transformed from the ARX model, called the "flexible model" in the following discussion. The flexible model in this study is based on a translog cost function. As stated above, the cost function may be expressed in the translog functional form:

$$\begin{aligned}\ln C(w,q,t) \;=\; & \ln\beta_0 + \sum_{i=1}^{n}\beta_i \ln w_i + \beta_q \ln q + \beta_t t_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n}\beta_{ij}\ln w_i \ln w_j \\ & + \frac{1}{2}\beta_{qq}(\ln q)^2 + \frac{1}{2}\beta_{tt}\cdot t^2 + \sum_{i=1}^{n}\beta_{iq}\ln w_i \ln q + \sum_{i=1}^{n}\beta_{it}\ln w_i\cdot t + \beta_{qt}\ln q\cdot t + \epsilon\end{aligned} \tag{23}$$

where, w_i is the price of the i-th factor of production. Technological progress is assumed exponential.[37] Using Shephard's lemma, the i-th factor cost share equation is

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[36]This model is transformed into ARMA by imposing $\Gamma(L)=0$.

[37]The original index of technology advances at a constant rate, such as e^1 in the year 1, e^2 in the year 2, and so forth; therefore, t, which is logarithm of the original index in the

$$S_i = \beta_i + \sum_{j=0}^{n} \beta_{ij} \ln w_j + \beta_{iq} \ln q + \beta_{it} t + \xi_i \tag{24}$$

where S_i is the share of the i-th factor in total expenditure. As stated in the previous section, the cross-price derivatives of the cost function must be symmetric. Therefore the cost function must be homogeneous of degree one in the factor prices, and the cost shares must sum to 1, the translog function has restrictions on the parameters such that $\beta_{ij} = \beta_{ji}$, $\sum_j \beta_{ij} = 0$, $\sum_i \beta_{ij} = 0$, and $\sum_i \beta_i = 1$. The vector representation of the share equations with the disturbance, $\epsilon(t)$, is

$$S(t) = \mathrm{B}X(t) + \epsilon(t) \tag{25}$$

where the vector $S = [S_1, S_2, \cdots, S_n]^T$, the vector $X_i = [1, \ln w_1, \cdots, \ln w_n; \ln q, t]$, B is the n x m matrix with the i-th row such that $[\ \beta_i,\ \beta_{i1},\ \beta_{i2}, \cdots\ \beta_{in},\ \beta_{iq},\ \beta_{it}\ ]$, and the n x 1 matrix of the disturbance $\epsilon(t)$ is independently and identically distributed over time. The parentheses of t represent the time index. In this equation, restrictions on parameters are

$$i'\mathrm{B} = (1\ 0 \cdots 0), \qquad i'\epsilon(t) = 0 \quad \text{for all } t \tag{26}$$

where i is a unit vector with appropriate dimensions.

This static share model, which is applied by previous translog studies, implicitly assumes that $S(t)$ and $X(t)$ are stationary. As Harvey (1990) mentioned, many economic data are nonstationary, so that the assumption of stationarity is invalid. If either or both of $S(t)$ and $X(t)$ are nonstationary and integrated of order one, this model cannot be estimated without

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Taylor's approximation, grows such as 1, 2, ·.

testing and imposing cointegration among the variables to make the model stationary. Stationarity issues are discussed in more detail in the chapter 4.

Also, the static model assumes that current changes in the variables affect only current shares. However, this assumption may not hold; changes in some independent variables affect the shares in the following periods or the levels of the current shares may be dependent in their previous levels. Thus, the share equations are transformed into a lagged model. Let $\Phi^*(L)$ and $\Gamma^*(L)$ be lag variables on $S(t)$ and $X(t)$.

$$\Phi^*(L)\, S(t) \;=\; \Gamma^*(L)\, X(t) \;+\; \epsilon(t) \tag{27}$$

This model has *ad hoc* characteristics, since it is not derived from the original translog model but from the share equations. Thus, this model has limited implications for original cost function. However, this model is useful in estimation, since it has a relatively small number of parameters and maintains a linear form. Also, it still keeps many of the flexible properties of the translog model, such as variable elasticities of substitution and nonhomotheticity. A general form of an error correction model is derived from this model as follows.

Define $\Phi(L)$ and $\Gamma(L)$:

$$\begin{aligned}
\Phi(L) &= \sum_{j=1}^{p-1}\sum_{i=0}^{j} \Phi_i L^j \\
&= (\Phi_0^* + \Phi_1^*)\,L + (\Phi_0^* + \Phi_1^* + \Phi_2^*)L^2 + \dots + (\Phi_0^* + \Phi_1^* + \dots + \Phi_{p-1}^*)L^{p-1} \\
\Gamma(L) &= \sum_{j=0}^{q-1}\sum_{i=0}^{j} \Gamma_i L^j \\
&= \Gamma_0 + (\Gamma_0^* + \Gamma_1^*)L + (\Gamma_0^* + \Gamma_1^* + \Gamma_2^*)L^2 + \dots + (\Gamma_0^* + \Gamma_1^* + \dots + \Gamma_{q-1}^*)L^{q-1}
\end{aligned} \tag{28}$$

for $p>1$ and $q \geq 1$. The differences of $\Phi(L)$ and $\Gamma(L)$ are

$$\begin{aligned} \Delta\Phi(L) &\equiv \Phi(L) - \Phi(L)L \\ &= (\Phi_0^* + \Phi_1^*)L + \Phi_2^* L^2 + \Phi_3^* L^3 + \dots + \Phi_{p-1}^* L^{p-1} - (\Phi_0^* + \dots + \Phi_{p-1}^*) L^p \\ &= \Phi^*(L) - \mathbf{A} L^p + \Phi_0^* L - I \\ \Phi^*(L) &= \Delta\Phi(L) + \mathbf{A} L^p - L + I \\ \Phi^*(L) S(t) &= \Phi(L)\,\Delta S(t) + \mathbf{A} S(t-p) - S(t-1) + S(t) \\ &= \Phi(L)\,\Delta S(t) + \mathbf{A} S(t-p) + \Delta S(t) \end{aligned} \tag{29}$$

where $\mathrm{A} = \sum_{i=0}^{p-1} \Phi_i^*$. Similarly,

$$\begin{aligned} \Delta\Gamma(L) &\equiv \Gamma(L) - \Gamma(L)L \\ &= \Gamma_0^* + \Gamma_1^* L + \Gamma_2^* L^2 + \dots + \Gamma_{q-1}^* L^{q-1} - (\Gamma_0^* + \Gamma_1^* + \dots + \Gamma_{q-1}^*) L^q \\ &= \Gamma^*(L) - \Gamma_q^* L^q - (\Gamma_0^* + \Gamma_1^* + \dots + \Gamma_{q-1}^*) L^q \\ &= \Gamma^*(L) - \Pi L^q \\ \Gamma^*(L) &= (\Gamma(L) - \Gamma(L)L) + \Pi L^q \\ \Gamma^*(L) X(t) &= \Gamma(L)\,\Delta X(t) + \Pi X(t-q) \end{aligned} \tag{30}$$

where $\Pi = \sum_{i=0}^{q-1} \Gamma_i^*$. Substituting these into the original equation, it is transformed as

$$\Phi(L)\,\Delta S(t) + \mathrm{A}\, S(t\text{-}p) + \Delta S(t) = \Gamma(L)\,\Delta X(t) + \Pi\, X(t\text{-}1)$$

$$\Delta S(t) = -\,\Phi(L)\,\Delta S(t) - \mathrm{A}\;\; S(t\text{-}1) + \Gamma(L)\,\Delta X(t) + \Pi\, X(t\text{-}1)$$

$$\Delta S(t) = -\,\Phi(L)\,\Delta S(t) + \Gamma(L)\,\Delta X(t) - \mathbf{A}\,[S(t\text{-}p) - \mathbf{B}\, X(t\text{-}1)]$$

where $\mathbf{B} = \mathbf{A}^{-1}\,\Pi$. This is a general expression of an error correction model transformed from the ARX model. This model has the same flexibility in dynamic structure as the original ARX in terms of dynamic structure. In the case of first-order model (*i.e.*, p=q=1), A = - (I + Φ_1), $\Gamma(L) = \Gamma_1$, $\Pi = \Gamma_0 + \Gamma_1$, and Φ is null for $p = 1$, so that

$$\Delta S(t) = \Gamma_0 \Delta X(t) - \mathbf{A}[S(t-1) - \mathbf{B}X(t-1)] + \epsilon(t) \tag{31}$$

In this expression, the coefficients B represent the steady state relationship, $S = \mathrm{B}\,X$ and Γ_0 and A represent terms for short-run adjustment, which will disappear in long run equilibrium. Thus, this model is distinct from the model **(26)** in the sense that coefficients in this model show long-run effects of variables, while coefficients in the latter model represents short-run effects.

Since the cost shares add up to one, differences of the shares ΔS_i add up to zero. To insure that the sum of the right-hand side equations is equal to zero, the column sums of Γ and A must be zero. Also, since $S = \mathrm{B}\,X$ for the steady state condition, the sum of elements in the first column of B is equal to one, and the other column sums of B are zero. These restrictions are called the 'adding-up' restrictions. The adding-up restrictions imply that equations in the model are singular, therefore, it cannot be estimated unless some modifications are made. To make the estimation feasible, first, one of the shares is dropped from the system. As a result, $\Delta S(t)$ and $S(t\text{-}1)$ will be $(n\text{-}1)\text{x}1$ vectors, and correspondingly, the last row of A being deleted. Since the sum of elements in the row of $n\text{x}n$ matrix, A also equals to zero, the ij-element of the $n\text{x}n$ matrix A is modified as $\alpha^*_{ij} = (\alpha_{ij} - \alpha_{im})$ for all $i, j = 1, \cdots, n\text{-}1$, so that the new matrix A^* becomes $(n\text{-}1)$ x $(n\text{-}1)$. Also, restrictions for symmetry and homotheticity of input prices are imposed in the matrix B. Thus, $\beta_{ij} = \beta_{ji}$ for all i and j, and $\ln(x_i / x_n)$ is used for the independent variables (i=1,$\cdots$,n). In addition, since the model has lags, the first element of ΔX, the constant term disappears, and $\Delta \mathrm{T}$ is equivalent to the constant, therefore, the first and last columns of Γ will be deleted.

Since this model is highly non-linear, estimation may be difficult. The model can be transformed into a linear form. The first order form of the equation

$S(t) = -\Phi_1 S(t\text{-}1) + \Gamma_0 X(t) + \Gamma_1 X(t\text{-}1) + \epsilon(t)$ may be transformed into

$$(I+\Phi_1)^{-1}S(t\text{-}1) = -(I+\Phi_1)^{-1}\Phi S(t\text{-}1) + (I+\Phi_1)^{-1}\Gamma_0 X(t\text{-}1) + (I+\Phi_1)^{-1}\Gamma_1 X(t\text{-}1) + \epsilon(t)$$

$$(I+\Phi_1)^{-1}(I+\Phi_1)S(t\text{-}1) = -(I+\Phi_1)^{-1}\Phi_1 \Delta S(t) + (I+\Phi_1)^{-1}(\Gamma_0+\Gamma_1)X(t)$$

$$-(I+\Phi_1)^{-1}\Gamma_1 \Delta X(t\text{-}1) + (I+\Phi_1)^{-1}\epsilon(t)$$

$$S(t) = F\Delta S(t) + BX(t) - G\Delta X(t-1) + \xi(t) \qquad \textbf{(32)}$$

where $F = -(I + \Phi_1)^{-1}\Phi_1$, $B = (I + \Phi_1)^{-1}(\Gamma_0 + \Gamma_1)$, $G = (I + \Phi_1)^{-1}\Gamma_1$, and $\xi(t) = (I + \Phi_1)^{-1}\epsilon(t)$. Unlike the previous error correction model, this transformed model is linear in parameters so that estimates are easily obtained. Also, this model includes coefficients representing the long-run relationship (B), which is the same as what appears in the error correction model. Yet, compared to the error correction representation, the functional form of this linear dynamic model expresses less explicit implications for long-run and short-run factor adjustment.

Conclusion

In this chapter, we have reviewed the theory of duality and dynamic econometric models. Then, a dynamic model was derived from a system of share equations based on a translog cost function. This model is flexible in terms of functional properties (*i.e.*, elasticities of substitution and homotheticity) and allows for a flexible ad hoc dynamic adjustment process. Also, the model is useful for estimation of long-run output elasticities since it permits short-run disequilibrium but still imposes long-run equilibrium.

The model is implicitly assumed to be stationary so that it can be estimated using standard econometric procedures. This model contains levels of variables as well as first differences.

Thus, the model is valid only if either all data are either stationary in levels or they are not stationary but a linear combination of the data is stationary (*i.e.*, cointegrated). Stationarity of data is discussed in detail in the next chapter.

CHAPTER 4

DATA AND PRELIMINARY TESTING

4.1 Data

This study uses annual data on Japanese agriculture for the period 1951 to 1992.[38] It is assumed that agricultural production in Japan uses four kinds of inputs (*i.e.*, land, labor, agricultural chemicals, and capital inputs) to produce a composite output.

The prices of labor and land cannot be obtained directly from a market since these prices include opportunity costs, such as family labor and rent for own land.[39] Although there is a market for hired labor, hired labor accounts for less than 2 percent of the total farm labor in Japan.[40] Therefore, wages for hired labor do not adequately represent wages for the total farm sector. Rather, this study uses labor costs per working hour as labor prices. The costs include opportunity costs of family labor and managerial labor, as well as hired labor. Labor cost per hour is obtained by dividing labor costs per unit of production in a year by labor

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[38]Japan was in disorder during an intermittent war (1894-1945) and several years after the war. Thus, this study uses the data after 1951 when Japan became officially independent and the economy normalized.

[39] Kuroda (1987, 1988) used wages for hired labor as a proxy for wages of family labor, while Kako (1979) used labor costs per hour working for prices of labor. We follow the latter in this paper.

[40]The proportion of hired labor in the whole farm labor is calculated by average working days in a year of a hired worker times the number of the hired workers in Japan divided by average working days of a farmer times the total number of farmers in Japan.

hours per unit of production in a year. Similarly, land prices are obtained as rental costs per hectare in a year, which includes rent for farmers' own cultivated land as well as rent paid to other owners by the farmer. The labor and land prices are collected in terms of five product groups--rice, wheat and barley, potatoes, vegetables, and fruits.[41] Since many kinds of vegetables are produced in Japan, costs for vegetables are estimated in terms of the five major products--cucumbers, eggplant, tomatoes, cabbage, and Japanese radishes (*Daikon*). Similarly, two major fruit products in Japan, oranges and apples, are used to represent for fruits. The original data are obtained from the "Survey on Production Cost of Agricultural, livestock and Sericultural Products" collected by the Statistics and Information Department, Ministry of Agriculture, Forestry, and Fisheries (JMAFF). Estimated labor and land prices for each crop are aggregated into total labor and land prices, by the weights of values of production for each crop.

Prices of chemical and capital inputs are collected from the factor price lists in the "Survey on Prices and Wages in Rural Areas" (JMAFF). The chemical input prices are calculated by weighted averages of the fertilizer prices and agricultural chemicals for each year.[42] Prices of capital inputs are estimated as aggregate prices of agricultural machines and tools, heat, lights, and other energy, farm buildings, other infrastructures, seeds, fees, agricultural clothing, and miscellaneous materials. Averages of chemical and capital input prices are obtained by weighting by production expenditures for each item in terms of rice, wheat,

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[41]Barley produced in Japan includes "two-row barley," "six-row barley," and "naked barley."

[42]"Agricultural chemicals" include pesticides, insecticides, and all other chemical inputs but fertilizers.

potatoes, vegetables, and fruits, which is obtained from the "Farm Household Economy Survey" (JMAFF).

Output quantities are estimated as the total value of output of rice, wheat and barley, potatoes, vegetables, and fruits, divided by the prices for the products. The total values of output are obtained from the "Agricultural Output and Income Survey" compiled by JMAFF. Also, a time trend is used as a proxy variable for technological progress. The technology is assumed to grow at a constant rate each year. All prices of the factors and outputs are normalized so that values in the base year are equal to 1. Production costs for each input are obtained from the "Survey on Production Cost of Agricultural, livestock and Sericultural Products"(JMAFF).[43] Then, cost shares are calculated as costs for the factor used for all products, divided by the total costs.

4.2 Stationarity and Cointegration

Stationarity

A series is defined as stationary if the probability laws of the process do not change over time. Let $Z(t_i)$ be a distribution at time t_i. Then, if the joint distribution of $Z(t_1)\ Z(t_2) \cdots Z(t_n)$ is the same as the joint distribution of $Z(t_{1-k})\ Z(t_{2-k}) \cdots Z(t_{n-k})$ for t_i and k ($i = 1 \cdots n$), that is, the distribution is not changing over time, the distribution is called strictly stationary. Whereas this condition may hold in cross-section data, it is not often applicable in time series data. The concept of stationarity used in this study is weak stationarity, where the mean and variance are constant over time and autocovariance depends only on the difference between

[43]The costs include opportunity costs of labor and land.

the two periods. For example, in the model

$$y(t) = \alpha + \beta x(t) + \gamma y(t-1) + \epsilon(t), \tag{33}$$

$y(t)$ is explained by its past value, the other explanatory variables $x(t)$, and the innovation $\epsilon(t)$. By transforming this equation

$$y(t) = \sum_{i=0}^{\infty} \gamma^{i} [\alpha + \beta x(t-i) + \epsilon(t-i)] \tag{34}$$

Therefore, the variance of y(t) is

$$\mathrm{Var}[y(t)] = \sum_{i=0}^{\infty} (\gamma^{i})^2 = \sigma^2 / (1 - \gamma^2) \tag{35}$$

where σ^2 is the variance of the disturbance. In order to ensure a finite and positive variance of $y(t)$, γ must be inside of the unit circle.

A stationary series and a nonstationary series have distinct empirical difference. A stationary series move up and down around the mean, while a nonstationary series tends to keep growing or declining. A stationary series has a finite variance and an autocorrelation diminish as the lag increases. On the other hand, a variance of nonstationary series grows over time and an autocorrelation stays at one. A shock on stationary series gives a transitory effect so that the effect declines over time, and the series will return around the original mean. However, in terms of nonstationary data, effect of a shock would be permanent.

Unit Root

Let $v(t)$ be a stationary process, then an AR(1) model is expressed as

$$y(t) = \rho y(t\text{-}1) + v(t)$$

If $\rho=1$, it is called a unit root process:

$$y(t) = y(t\text{-}1) + v(t)$$

Granger and Newbold (1974) pointed out that the conventional t test for a unit root would induce an incorrect conclusion. Dickey and Fuller (1979, 1981) showed that in a case of a unit root, estimate of ρ is biased downward and the variance of the estimator converged more rapidly than the estimator in a case of the usual ordinary least squared. It implies that a conventional test would reject hypothesis that $\rho=1$ incorrectly. They derived a set of critical values for testing this hypothesis using a conventional t-test procedure (Dickey and Fuller, 1979) as well as a F-test (Dickey and Fuller, 1981).

Integration

If a variable becomes stationary after being first differenced d times, the series is integrated of order d, denoted $I(d)$. Thus, a stationary variable is integrated of order zero, and a variable which must be differenced once to be made stationary is integrated of order one. Most economic data are $I(0)$ or $I(1)$, and many of them are $I(1)$ (Harvey, 1990).[44] If $x(t) \sim I(1)$, then $\Delta x(t)$ is $\sim I(0)$, thus, differencing will create stationarity by removing components for random walk and trend.[45]

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[44] Higher order or fractional integration is also possible.

[45] Hendry (1991) suggested that differencing may lose some valuable information of the data.

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Cointegration

There are several rules in terms of linear combinations of integrated series. If all components of the vector series, $x(t)$ are $I(0)$, then any linear combination of $x(t)$ is $I(0)$. If all components of $x(t)$ are I(d), then it is generally true that any linear combination of $x(t)$ is $I(d)$. Yet, it is possible that the linear combination will be $I(d - b)$, where $b>0$. In this special case, the components of $x(t)$ are said to be cointegrated of order d, b, denoted $x(t) \sim \mathrm{CI}(d, b)$ and the vector to generate this linear combination is called the cointegrating vector. If $x(t)$ has N components, and has r linearly independent cointegrating vectors ($r \leq N$-1), α is the $N \times r$ matrix.

In terms of the flexible dynamic model presented in the previous chapter,

$$\Delta S(t) = \Gamma\, \Delta X(t) - \mathrm{A}[S(t\text{-}1) - \mathrm{B}\, X(t\text{-}1)] + \epsilon(t),$$

if S and X are $I(1)$, then ΔS and ΔX are $I(0)$. Since the left-hand side of the equation is $I(0)$, all terms in the right-hand side must be $I(0)$ to have stationary error terms $\epsilon(t)$, thus, $S(t$-1) and $X(t$-1) must be cointegrated with cointegrating vectors B.

In economic theory, the notion of equilibrium implies that series cannot continue to drift apart. Indeed, nonstationary series in many cases are found to be moving together in the long-run. This idea is captured by cointegration. For example, it is sometimes observed that commodity prices that seem unrelated to each other move together. Such a price co-movement may be caused by a certain common macroeconomic shock (*e.g.*, money supply and interest rate) and speculation in the commodity market (Myers, 1994). Cointegration represents a certain long-run relationship between the data.

Tests for Unit Roots and Cointegration

In order to detect the individual variables are $I(0)$ or $I(1)$, the Dickey-Fuller test for unit roots is used as follows:

$$\Delta x_i(t) = c + \gamma t + \rho_i x_i(t-1) + \epsilon(t).$$

where x includes variables for prices of labor (L), land (D), chemical (CH), and capital (K); output (Q); and shares of labor (S_L), land (S_D), chemical (S_{CH}), and capital (S_K).[46] A constant term c and a time trend variable t are included in the equation.

In order to investigate cointegration among variables, this study follows Engle and Granger's (1987) two-step estimation procedure: First, using the OLS model, one of the variables is regressed on the other then it is tested whether there is a unit root in the residuals. Since the OLS seeks coefficients that reduce the variance of the residuals, the regression efficiently produces the estimate of the cointegration vector. The linear combination of the variables other than the cointegrated vector will have infinite variances. If the series are not cointegrated, there must be a unit root in the residuals, therefore, they are found to be nonstationary. Dickey and Fuller (1979, 1981) showed that the variance of the estimate under the null hypothesis in the unit root equation converges to its probability limit more rapidly than the ordinary estimators. Critical values for the t-test different from the ordinary tests are provided by them.

This Dickey-Fuller test requires the disturbance to be serially uncorrelated. To check whether or not there exists any serial correlation in the error of the above equation, the Q-

[46]The augmented Dicky-Fuller tests include lags of $\Delta x_i(t)$.

statistic test proposed by Ljung and Box (1979) is used.[47] The Ljung-Box Q-statistics are computed by the following equations.

$$Q = T(T+2)\sum_{j=1}^{p} [\gamma_j^2/(T-j)],$$
$$\text{where} \quad \gamma_j = \frac{\sum_{t=j+1}^{T} \epsilon(t)\,\epsilon(t-1)}{\sum_{t=1}^{T} \epsilon(t)^2} \qquad \textbf{(36)}$$

and p is the number of the lags for the test.

As an alternative test for serial correlation, Breusch (1978) and Godfrey (1978) proposed a Lagrange multiplier test. The null hypothesis of this test is that errors are not serially correlated and the alternative hypothesis is the errors take an autoregressive or moving average form. The test is carried out by regressing the OLS residuals $\epsilon(t)$ on the independent variables and the lagged errors.

As a result of the Ljung-Box tests, serial correlations are detected in the variables D, CH, and K. Also, the serial correlations are found in L, D, CH, and K in the Breusch-Godfrey tests. As there are no serial correlations in the share values and the output levels, the Dickey-Fuller test can be applied directly to these variables. The critical values for this test are -3.50 at 5 percent and -3.18 at the 10 percent in a case of T=50. All shares as well as the output show relatively high values. However, all of these estimates but S_{CH} do not reach to the critical values, so that the hypothesis of a unit root is rejected only for S_{CH}.

Also, the hypothesis of unit roots in the autocorrelated variables (i.e., L, D, CH, and K) is tested using procedures proposed by Phillips (1987) and Perron (1988). The Phillips-

[47]The Ljung-Box Q-test is a refinement of the original Q-test proposed by Box and Pierce (1970).

Perron test takes account of serial correlation and potential heteroscedasticity in the errors. Let σ_ρ and τ_ρ be the standard error and the t-statistic of ρ^* and s^2 is the variance of the residuals from the Dickey Fuller regression, so that

$$s^2 = (T-2)^{-1}\sum_{t=1}^{T} \epsilon(t)^2 \ ; \qquad \lambda^2 = \gamma_0 + 2\sum_{j=1}^{q} \gamma_j [1 - j/(q+1)] \tag{37}$$

where γ_j is the autocovariance of the OLS residuals between the time t and the time $t-j$, thus,

$$\gamma_j = T^{-1}\sum_{t=j+1}^{T} \epsilon(t)\,\epsilon(t-j) \tag{38}$$

Then, the Phillips-Perron t-statistic is computed by

$$Z_\tau = \frac{\gamma_0^{1/2} \cdot \tau_\rho}{\lambda} - \frac{T \cdot \sigma_\rho (\lambda^2 - \gamma_0)}{2\, s \cdot \lambda} \tag{39}$$

And, the Phillips-Perron statistic for the coefficient ρ is

$$Z_\rho = T \cdot \rho^* - \frac{T^2 \cdot \sigma_\rho^2 (\lambda^2 - \gamma_0)}{2\, s^2} \tag{40}$$

In the above equations, we use truncation of 2, 4, and 6 lags. Under the limited number of observations, we cannot use larger number of lags as it reduces efficiency in the estimation. The critical values in the Phillips-Perron tests are equivalent to those in the Dickey-Fuller test based on estimated OLS autoregressive coefficients and *t* statistics. The critical value of the Phillips-Perron $T\rho^*$ test (Z_ρ) at the 5 percent level is −19.8 in a case of 50 samples, while the critical value of the Phillips-Perron *t* test (Z_t) is −2.93 (Fuller 1976, p.371). In the model with 4 lags, for example, computed Z_ρ for L, D, CH, and K are −6.51, −1.26, −5.54, and −4.54, while those of Z_t are −1.58, −0.43, −1.71, and −1.25, respectively. Thus, all of these estimates are lower than the corresponding critical levels.

F-tests are also applied under the null hypotheses of zero slopes of the autoregressive variable and the trend variable ($\rho=\gamma=0$). As seen in the Table 4.2.1, all estimated F-statistics are far below the critical value of 6.73. The tests do not reject the hypothesis of unit roots in all variables, except share of chemical. Therefore, at least all series for factor prices and output are concluded to be nonstationary.

Table 4.2.1 The Dickey Fuller Tests and the Phillips-Perron Tests of Unit Roots in the Variables.

	L	D	CH	K	Q	S_L	S_D	S_{CH}	S_K
ρ	-0.062	-0.009	-0.065	-0.029	-0.209	-0.241	-0.337	-0.576	-0.111
SE(ρ)	0.076	0.064	0.053	0.063	0.091	0.094	0.123	0.150	0.068
t-statistic of ρ	-0.821	-0.135	-1.229	-0.467	-2.304	-2.575	-2.745	-3.838	-1.640
Z(ρ) with p=2	-3.567	-0.056	-3.764	-2.424	-7.322	-9.096	-13.578	-21.948	-4.681
Z(t) with p=2	-1.051	-0.019	-1.431	-0.804	-2.200	-2.512	-2.723	-3.745	-1.658
Z(ρ) with p=4	-6.509	-1.258	-5.536	-4.541	-7.003	-10.172	-12.147	-24.142	-4.019
Z(t) with p=4	-1.579	-0.429	-1.712	-1.252	-2.212	-2.589	-2.589	-3.867	-1.561
Z(ρ) with p=6	-7.367	-1.769	-6.345	-5.088	-6.251	-10.925	-18.706	-23.295	-3.178
Z(t) with p=6	-1.729	-0.569	-1.827	-1.340	-2.214	-2.631	-3.152	-3.819	-1.430
F-statistic	0.729	1.806	0.797	0.790	3.245	3.320	3.500	5.460	2.631

Note: ρ=autoregressive coefficient of the OLS with constant and trend variables; SE(ρ)=standard error of ρ; Z(ρ)=Phillips-Perron statistic of the autoregressive coefficient with p-th order lag truncation, ρ; Z(t)=Phillips-Perron statistic of the *t* value of ρ with p-th order lag truncation. F-statistic is based on the test under hypothesis of zero coefficients of the autoregressive and the trend.

Critical values for Z(ρ) and Z(t) at 5% levels are −19.80 and −3.50 (T=50); Critical values for the Dickey-Fuller test based on the OLS F statistic is 6.73 (T=50).

In terms of stationarity of the factor shares, hypothesis of a unit root in chemical share is rejected at 1 percent by the Phillips-Perron test, while the hypotheses of a unit root in land share is only rejected at 10 percent in the Phillips-Perron ρ test with 6-lag truncation; and the tests could not reject for labor and land shares.[48] Based on these results, and the fact that factor shares are bounded between zero and one, we conclude that all factor shares are stationary.

Factor shares are considered to be stationary because they fluctuate within a certain range and could not keep growing. It is always strictly bounded between 0 and 1, so that it could not approach "too close" to the boundaries. Some temporary shocks, such as a price shock, may change the level of share temporary but it would not remain at a new level permanently even after the shocks are over. Variances of share would not grow toward infinity over time, since boundary of a share would not be widened over time. In this sense, the shares are expected to be stationary.

Still, it is possible that a share is trending in sample due to bias in technological change. Technological change bias is measured by $(\partial S_i/\partial t)(1/S_i)$, where S_i is i-th factor share and t is the time index (Binswanger, 1974). It clearly shows that a nonzero value of this estimate implies that the share variable has a trend, but the trend must die out as the share approaches zero or one.

The null hypothesis of noncointegration among the variables, L, D, CH, K, and Q is tested. The *t*-values of an OLS regression of the residual from the cointegrating regression

[48]The critical values for the Phillips-Perron Z_t test are -4.15 at 1 percent, -3.50 at 5 percent and -3.18 at 10 percent for 50 samples; similarly the critical values for the Z_ρ test are -25.7 at 1 percent, -19.8 at 5 percent, and -16.8 at 10 percent (Fuller, 1976).

on its lagged value, constant, and the time trend variable are -3.28, -0.78, and 0.84, while the *t*-value of the regression without the constant and the time trend is -3.27. Since the intercept and the coefficients on the trend variable should both be zero by construction, the test for cointegration is carried out without these variables. The Phillips-Perron Z(*t*) and Z(ρ) tests with 4 lags are -3.49 and -22.21, while their critical values are, respectively, -4.49 and -37.7 at 5 percent. Thus, the hypothesis of noncointegration is not rejected, concluding there is not cointegration among these variables.

The Durbin-Watson statistics from the cointegrating regressions may be used as another test of cointegration.[49] The cointegrating regression Durbin-Watson test examines whether an estimate of Durbin-Watson statistic is large enough from zero to reject the null hypothesis of noncointegration. The critical values, provided by Sargan and Bhargara (1983), are 0.446 for the lower limit and 1.518 for the upper limit for 51 observations at the 5 percent level, and 0.651 for the lower limit and 2.185 for the upper limit for 31 observations. Thus, estimated statistics of the model in this study are 1.609, 1.361, 1.424, and 1.488, so that the results are inconclusive.

Estimation

The models in this study have a set of the share equations. Since the share equations are singular, one equation is omitted.[50] The major estimation methods for system equations are

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[49]However, Engle and Granger (1987) argue that the test is not recommend since the critical value is so sensitive to the particular parameters within the null, although the CRDW tests might be used for a quick approximate result due to its simplicity.

[50]According to Barten (1969), the maximum likelihood estimates of the parameters are independent of the omitted cost share equation.

the full information maximum likelihood (FIML) method. The FIML estimates are sensitive to distribution of the errors.

Dynamic Process

The dynamic adjustment process is evaluated using the data: The maximized value of the likelihood functions (ln$L$) in the flexible dynamic model without the restrictions on parameters is 360.310, while the value of ln$L$ in the static translog model without the restrictions is 336.508. Since the likelihood ratio statistic $\lambda = -2\ (\ln L_0 - L_1)$ has chi-distribution with degrees of freedom of the number of constraints, where L_1 and L_0 are the maximized values of the likelihood functions with and without constraints. The critical value of the LR test is 42.98 at the 1 percent of significance. The computed value of the log likelihood function is 47.604. Therefore, the hypothesis of no dynamic process is rejected at the 1 percent level. Similarly, the value of ln$L$ in the flexible dynamic model with restrictions of symmetry and homotheticity is 355.675, while that in the static model is 303.926. The LR ratio 103.498 is above the critical value; thus, the dynamic process is also supported in the model with restrictions.

Conclusion

This chapter has discussed stationarity of data, as well as estimation methods. Now, it is well known that many time series economic data are nonstationary. If a model that contains nonstationary series is used for an econometric analysis, a statistical test may reject incorrectly a hypothesis, although there is, in fact, no relationship about the hypothesis. A model used in this study contains levels of variables as well as their first differences. If data used in this study are nonstationary, then they must be cointegrated so that linear combination of series is stationary. Dickey Fuller tests and Phillips-Perron tests for unit roots in the data show series of factor prices and output are not stationary, while at least one of the shares is stationary. Although these tests could not reject hypothesis of stationarity in some share data, stationarity of these data is suspected. If one of the shares is nonstationary, the sum of these shares cannot be 1. Also, a series of share data is strictly bounded between 0 and 1, so it cannot keep growing over time. Also, the Phillips-Perron tests for hypothesis of noncointegration are carried out. The test results found that the data used in the estimation are not cointegrated.

CHAPTER 5

RESULTS

This chapter presents results of estimating the model developed in previous chapters, and then the model's conformity with economic theory is tested. This is followed by a section which evaluates economic implications of the results, including output elasticities of factor demand and partial elasticities of factor substitution.

5.1 Specification Tests

Concavity

Cost functions are concave in factor prices. In the translog cost function, each element of the Hessian matrix is a function of w_i, but the matrix is not necessarily negative semi-definite. For $i \neq j$, the ij-th element of the Hessian is

$$\frac{\partial^2 C}{\partial w_i \partial w_j} = \frac{1}{w_i}\frac{1}{w_j}\frac{\partial \ln C}{\partial \ln w_i}\frac{\partial C}{\partial \ln w_j}C + \frac{1}{w_i}\frac{1}{w_j}\frac{\partial^2 \ln C}{\partial \ln w_i \partial \ln w_i}C = \frac{\beta_{ij} + s_i s_j}{w_i w_j}C \tag{41}$$

where C, w_i, and s_i are the total cost, the factor price, and the i-th cost share for i=1,$\cdots$,n. Also, the i-th diagonal element is

$$\frac{\partial^2 C}{\partial w_i^2} = \frac{1}{w_i^2}\frac{\partial \ln C}{\partial \ln w_i}\frac{\partial \ln C}{\partial \ln w_i}C + \frac{1}{w_i^2}\frac{\partial^2 \ln C}{\partial \ln w_i^2}C - \frac{1}{w_i^2}\frac{\partial \ln C}{\partial \ln w_i}C = \frac{\beta_{ii} + s_i^2 - s_i}{w_i w_j}C \tag{42}$$

The Hessian matrix is expected to be negative semi-definite at least at the neighborhood of the base year. Since in the base year, $w_i = w_j = 1$, and C is canceled in both equations, we need only check the signs of $\beta_{ij}+s_i\, s_j\ (i \neq j)$ and $\beta_{ii}+s_i^2-s_i\ (i=j)$. Computed Hessian matrices are presented in Appendix Tables A.5.1.1, A.5.1.1, and A.5.1.3 and the eigenvalues are in Appendix Table A.5.1.4. The tests fail to show the concavity in the factor prices.[51]

Symmetry and Homotheticity Restrictions

Symmetry and homotheticity conditions, which must be satisfied for parameters representing long-run relationships, are checked by likelihood ratio tests. Since the flexible dynamic model is based on a static translog model, the term representing the long-run equilibrium must comply with same restrictions as the static model. The maximized values of likelihood functions of the flexible models without restrictions, with symmetry restrictions, with homotheticity restrictions, and with symmetry and homotheticity restrictions together are 360.310, 358.284, 357.228, 355.675, respectively. Therefore, the likelihood ratio statistic of symmetry restrictions on unrestricted model is 4.052, and of homotheticity restrictions is 6.164. Also, the statistic of both restrictions on unrestricted model is 4.635. Since 95 percent of the critical value in the chi-squared for 9 constraints is 16.92 and the value for 18 restrictions is 28.87, the symmetry and homotheticity restrictions are not rejected at the 95 percent level. Thus, the results show that the unrestricted model conforms to economic theory in terms of symmetry and homotheticity conditions.

Thus, both restrictions are rejected at a 5 percent level, which implies that the static

[51] Antle and Capalbo (1984, p.76) argued that many empirical applications involving translog fail these concavity conditions.

translog model does not comply with economic theory in terms of the restrictions on parameters. The maximum value of the log likelihood of the share equations in the static translog model without symmetry and homotheticity restrictions is 336.508, the value with symmetry restrictions is 310.234, and the value with symmetry and homotheticity restrictions is 302.958.

The restrictions for the Cobb-Douglas function on the translog model are rejected at 99 percent of significance. Therefore, the translog form is supported in terms of the flexibility. The homotheticity restrictions of the Cobb-Douglas are also rejected at 99 percent. Thus, the Cobb-Douglas model does not satisfy the homotheticity requirement.

5.2 Estimates and Elasticities

The estimated parameters in the models derived in the previous chapter are exhibited in Appendix Tables A.5.2.1. Using these estimates, the following section calculates elasticities of factor demand, substitution, and technological change. These estimates represent long-run effects that show how shocks on an economy might change production structure after all factors are adjusted to their equilibrium levels.

Output elasticity of factor demand is defined as a percent change in the input brought about by a 1 percent change in the output supplied. Let C($\boldsymbol{w}$, q) be a twice differentiable cost function where $\boldsymbol{w}$ and q are the n x 1 vectors of the factor prices and the output level, respectively. With the twice differentiable production function, a cost minimization problem is expressed as

$$\min C = \boldsymbol{w}\boldsymbol{x}$$

$$\text{subject to } f(\boldsymbol{x}) = q$$

Then, the first order condition is

$$w_i - \lambda f_i(x) = 0$$

$$q - f(x) = 0$$

Differentiating these equations with respect to q, we have the following matrix representation:

$$\begin{bmatrix} \lambda f_{11} & \lambda f_{12} & \cdots & \lambda f_{1n} & f_1 \\ \lambda f_{21} & \lambda f_{22} & \cdots & \lambda f_{2n} & f_2 \\ \vdots & \vdots & \cdots & \vdots & \vdots \\ \lambda f_{11} & \lambda f_{12} & \cdots & \lambda f_{1n} & f_n \\ f_1 & f_2 & \cdots & f_n & 0 \end{bmatrix} \begin{bmatrix} \partial x_1/\partial q \\ \partial x_2/\partial q \\ \vdots \\ \partial x_n/\partial q \\ \partial \lambda/\partial q \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ 1 \end{bmatrix} \tag{43}$$

Thus,

$$\frac{\partial x_i}{\partial q} = \frac{F_{ni}}{|F|} \tag{44}$$

where $|F|$ and F_{ni} are the determinant and the cofactor of the ni-th element of the $(n+1)$x$(n+1)$ matrix of the above equation. Therefore, the output elasticities of factor demand $[\partial x_i/\partial q][x_i/q]$ cannot be assumed to be the same for all factors. Furthermore, while the concave production function has a Hessian with a negative determinant, the sign of the cofactor of the matrix may be positive or negative, depending on the values of the second partial f_{ij}.[52] Thus, the signs of the output elasticities of factor demand are generally undetermined.

In the case of marginal cost of the production equal to the average cost at long-run

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[52] If it is negative, the factor is called an inferior factor. As the output level decrease, the factor demand will increase for a certain range of the output change. Unskilled labor in manufacturing is one of the examples.

equilibrium, the output elasticity of demand for the i-th factor (*i.e.*, $\eta_{iq}=[\partial x_i/x_i]/[\partial q/q]$) is obtained from the estimated parameters β_{iq} and the factor share S_i as

$$\eta_{iq} = \frac{\beta_{iq}}{S_i} + 1 \tag{45}$$

This is derived as follows: From Equation (1) and Shephard's lemma,

$$\partial C^* / \partial w_i = x_i^* (w, q)$$

$$\partial^2 C^* / [\partial w_i \partial q] = \partial x_i^* / \partial q$$

Thus,

$$\eta_{iq} = \frac{\partial^2 C^*}{\partial w_i \partial q} \frac{q}{x_i} \tag{46}$$

Using this equation and the definition of a factor share (*i.e.*, $S_i = [x_i w_i]/C$), also assuming the marginal cost equals the average cost at the equilibrium (*i.e.*, $C_q = C/q$), the coefficient of $\ln q \ln x_i$ in the translog cost function β_{iq} is transformed as follows:

$$\begin{aligned}
\beta_{iq} &= \frac{\partial^2 \ln C^*(w,q)}{\partial \ln w_i \partial \ln q} \\
&= \frac{\partial}{\partial q}\left[\frac{\partial C^*(w,q)}{\partial w_i} \frac{w_i}{C^*(w,q)}\right] q \\
&= \frac{\partial^2 C^*}{\partial w_i \partial q} \frac{w_i q}{C^*} - \frac{\partial C^*}{\partial w_i} \frac{w_i q}{C^{*2}} \frac{\partial C^*}{\partial q} \\
&= \frac{\partial^2 C^*}{\partial w_i \partial q} \frac{w_i q}{C^*} - \frac{x_i^* w_i (C^*/q) q}{C^{*2}} \\
&= \frac{\partial^2 C^*}{\partial w_i \partial q} \frac{w_i q}{C^*} - S_i
\end{aligned} \tag{47}$$

Therefore,

$$\frac{\partial^2 C^*}{\partial w_i \partial q} = \frac{C^*}{w_i q}(\beta_{iq} + S_i) \tag{48}$$

Substituting this into the definition of the output elasticity of factor demand, the equation for the elasticity is simplified as follows:

$$\begin{aligned} \eta_{iq} &= \frac{C^*(\beta_{iq} + S_i)}{w_i q}\frac{q}{x_i} \\ &= \frac{C^*(\beta_{iq} + S_i)}{w_i x_i} \\ &= \frac{\beta_{iq}}{S_i} + 1 \end{aligned} \tag{49}$$

If $\eta_{iq} > 1$, the production becomes *i*-th input-intensive as the output level increases, while the production becomes less intensive in the input if $\eta_{iq} < 1$. In other words, there are "economies of scale with respect to the *i*-th input" if $\eta_{iq} < 1$: The average amount of the input (*i.e.*, input requirement per unit output) declines as output increases. The elasticity may be greater than unity for one or some of the inputs, while all of them can be less than unity when there are increasing returns to scale. Note that the idea of "economies of scale with respect to an input" is different from usual "economies of scale," as explained in the next section.

Table 5.2.1 shows the output elasticities of factor demand estimated by the dynamic model with symmetry restrictions imposed on parameters (see Appendix Tables for other models). The elasticities are obtained by using the estimates and average share values of the inputs. Since equations for labor, land, and chemical are used in the estimation and the estimates of capital demand are obtained by adding-up restrictions, the standard errors of parameters in the capital equation are not available. Chemical use and capital use are inelastic with respect to output, while labor use and land use are elastic with respect to output. This result suggests that, as output increases, average use of labor and land per unit of output will increase under constant factor prices, while average use of chemical and capital per unit of output will decrease.

Table 5.2.1 Output Elasticities of Factor Demand Estimated in Various Models

	Labor	Land	Chemical	Capital
Flexible Dynamic Model	1.360 (0.265)	1.868 (0.636)	0.268 (0.375)	0.633
Linear Dynamic Model	1.312 (0.185)	1.827 (0.495)	0.341 (0.369)	0.670
Static Model	1.318 (0.107)	1.192 (0.287)	0.347 (0.204)	0.864

Note: Standard errors are in parentheses.

Although the standard errors of the output elasticities shown in Table 5.2.1 are estimated using standard errors obtained in FIML, as well as share values, the distribution of parameter errors in the nonlinear model is not necessarily normal (Hatanaka, 1994). Thus, confidence intervals of the elasticity estimates are obtained by a Monte Carlo simulation. In the simulation, error terms are obtained from the fitted residuals in the previous estimation, instead of assuming a specific type of distribution.[53] First, a value of a residual is picked randomly from a set of the fitted residuals in the error correction model estimated above. Then, the chosen values are inserted in the model and factor shares are calculated (*i.e.*, independent variables in the original equations). Since the model has lagged shares as

[53]This simulation is called *bootstrapping* (Hamilton, 1994).

dependent variables, actual lagged values of shares are used to obtain shares in the initial period (*i.e.*, 1952) and calculated shares are used as lagged variables in the rest of the years. Next, using a set of calculated shares and the actual series, the parameters are reestimated and saved. Using estimated parameters and shares, output elasticities of the factors are estimated. These procedures are iterated 10,000 times and the elasticities are sorted by values. Finally, the 5 percent confidence intervals of the elasticities are obtained.

Estimated 5 percent confidence intervals of the output elasticities are 1.018 to 1.783 for labor, 0.784 to 2.704 for land, and -0.303 to 0.864 for chemicals. Thus, the simulation found that the elasticity estimates are widely distributed. Furthermore the elasticities of labor are distributed in a relatively narrow range, while elasticities of land are distributed in a relatively wide range.

An elasticity of substitution measures how easily a given input can substitute for another input, holding the other input prices and the output level constant. This elasticity has important implications for factor demand: As an input price increases, the cost-minimizing firm replaces the input with other inputs, however the extent of this replacement varies among inputs. Graphically, the substitutability is represented by the curvature of isoquants. The greater is an elasticity of substitution, the flatter is the isoquant. In a case of a perfect substitute (*i.e.*, $\sigma=\infty$), the isoquant is flat. If no substitution between the inputs is possible (*i.e.*, $\sigma=0$), the isoquant becomes perpendicular (*i.e.*, the Leontief function).

The partial elasticity of substitution is defined as the proportional change in the ratio of amounts of input *i* and input *j* with respect to proportional change in the input price ratio where all other input prices and output are held constant.

$$\sigma_{ij} = \frac{\partial(x_i/x_j)}{\partial(w_i/w_j)} \frac{w_j/w_i}{x_i/x_j} \tag{50}$$

In an alternative form, Allen (1938) developed the partial elasticity of substitution,

$$\sigma_{ij} = \frac{\sum_{k=1}^{n} x_k f_k}{x_i x_j} \frac{F_{ij}}{|F|} \tag{51}$$

where x_i is the i-th factor of production; f_k is the derivative of the production with respect to k-th input; and F_{ij} is the ij-th cofactor of F, which is

$$F = \begin{bmatrix} 0 & f_i & \cdots & f_n \\ f_i & f_{11} & \cdots & f_{1n} \\ \vdots & \vdots & & \vdots \\ f_n & f_{nl} & \cdots & f_{nn} \end{bmatrix} \tag{52}$$

Uzawa (1964) showed that the Allen's partial elasticity of substitution (AES) is computed from the cost function $C(w, q)$[54]:

$$\sigma_{ij} = \frac{C \cdot (\partial^2 C)/(\partial w_i \, \partial w_j)}{(\partial C/\partial w_i)\,(\partial C/\partial w_j)} \tag{53}$$

Thus, in the translog cost function, the AES is obtained as:

$$\begin{aligned} \sigma_{ii} &= \frac{\beta_{ii}}{S_i S_j} + 1 - \frac{1}{S_i} \quad \text{for all } i \\ \sigma_{ij} &= \frac{\beta_{ij}}{S_i S_j} + 1 \quad \text{for all } i, j;\ i \neq j \end{aligned} \tag{54}$$

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[54]Binswanger (1974, AER) proved this without relying on homogeneity.

Own price elasticities of demand for factor i (ϵ_{ii}) and cross-elasticities of demand for factor i and factor j (ϵ_{ij}) are equivalent to the corresponding AES multiplied by the cost share of the input:

$$\begin{aligned} \epsilon_{ii} &= \frac{\beta_{ii}}{S_i} + S_i - 1 \quad \text{for all } i \\ \epsilon_{ij} &= \frac{\beta_{ij}}{S_i} + S_j \quad \text{for all } i,j;\ i \neq j \end{aligned} \tag{55}$$

The AES and price elasticities of the factor demand estimated in models with symmetry are presented in Table 5.2.2 (see Appendix Table A.5.2.6, A.5.2.7, and A.5.2.8 for detail). Again, the average share values are used for estimation. Results suggest that labor is a substitute for all other inputs, especially, for capital inputs. This is consistent with the previous argument that capital goods, like machinery, are used for labor-saving purposes. Chemical inputs are also found to be substitutes for labor and land. For instance, fertilizers are used for land-saving purposes and herbicides are used for labor-saving. On the other hand, land is a weak substitute for capital. Also, chemical and capital inputs are complementary to each other. This implies that, due to mechanization, greater use of fertilizers became available through deep tillage, as discussed in the chapter two.

In terms of price elasticities of factor demand, chemical price and capital price significantly affect labor demand. A one percent increase in prices of chemicals and capital will increase labor demand by 0.55 percent and 0.35 percent. This implies that decreasing chemical and capital prices after the 1960s contributed to reduce labor demand in Japanese agriculture.

Table 5.2.2 The Allen's Partial Elasticities of Factor Substitution Estimated by the Flexible Dynamic Model

	Labor	Land	Chemical	Capital
Labor	-1.451 (0.409)	0.433 0.688	6.781 (1.663)	-2.324 (1.543)
Land	1.509 (0.979)	-8.346 (1.651)	11.730 (3.981)	-9.165 (3.696)
Chemical	1.195 (0.578)	1.479 (0.970)	-4.548 (2.347)	-0.153 (2.181)
Capital	0.699	4.459	-9.830	5.537

Note: Standard errors are in parentheses.

Table 5.2.3 Own- and Cross-Price Elasticities of Factor Demand Estimated Flexible Dynamic Model

	Labor	Land	Chemical	Capital
Labor	-0.583 (0.164)	0.174 (0.277)	2.726 (0.668)	-0.934 (0.620)
Land	0.161 (0.105)	-0.893 (0.177)	1.255 (0.426)	-0.981 (0.395)
Chemical	0.189 (0.091)	0.234 (0.153)	-0.719 (0.371)	-0.024 (0.345)
Capital	0.232	0.484	-3.264	1.938

Note: Standard errors are in parentheses.

Economies of scale are such that long-run average cost exhibits a negative slope over a broad range of the output level.[55] Thus, the rate of change in total costs is less than that of output changes. The term "economies of scale" is similar to increasing returns to scale in the production process, although the idea is not identical. Increasing returns to scale means a

[55]Economies of scale is important, since, if it exists, development of larger scale of industry is justified to be appropriate for minimizing the average cost.

proportionate increase in all inputs makes the output increase in more than the same proportion. Thus, for a firm with increasing returns to scale, if all inputs are increasing at the same rates, more output can be produced from the same amount of inputs, therefore, average cost can be decreased.

The elasticity of scale measures relative changes in output resulting from a proportional change in all inputs. This is the reciprocal of the elasticity of total cost with respect to output along the expansion path (Hanoch, 1975). In the translog equation above, the cost elasticity is

$$\epsilon_C = \frac{\ln C}{\ln q} = \beta_q \qquad (56)$$

In terms of this equation, there are economies of scale if $\epsilon_c<1$; neutrality of scale if $\epsilon_c=1$; and diseconomies of scale if $\epsilon_c>1$. In the translog model, β_q does not appear in the share equations; only the original translog model contains this variable. Therefore, the economies of scale can be measured only in the static model, for which the complete translog equation may be included at the estimation. In the results of the static estimation, ϵ_c is found to be not significantly different from zero (Appendix Table A.5.2.14). Thus, we conclude that there is no evidence to show that economies of scale or diseconomies of scale exist in the Japanese agriculture.

Next, homogeneity and homotheticity of the production process are examined. In a production process that is homogeneous degree 1, if all inputs increase by the *k* times, the output level will also increase *k* times. In other words, if bundles of inputs X^1 and X^2 produce the same level of output y_0, then kX^1 and kX^2 will both produce $2q_0$. If a production function is homothetic, kX^1 will produce the same level of output as kX^2, but it is not necessarily $2q_0$.[56] Homothetic production and the homogeneous production both exhibit linear expansion paths. In such cases, factor ratios are constant as the output level changes under the constant input price ratio.[57] In terms of the translog cost function, the production is homothetic if $\beta_{iq}=0$; It is homogeneous if $\beta_{qq}=0$ as well as $\beta_{iq}=0$. Note that homotheticity in production process is sometimes referred as separability between input prices and output. If a production is homothetic, shares of inputs are independent of output levels.

In terms of the flexible dynamic model in this study, homotheticity may be tested under the hypothesis of $\beta_{iq}=0$ for all i. The hypothesis is tested by the likelihood ratio test. The maximum value of the log likelihood function in the restricted model is 355.784, while the value in the unrestricted dynamic model is 360.310. Thus, the hypothesis is rejected at the 5 percent level of significance. Since homogeneity could not be tested in the dynamic model, it is tested in the static translog model. The number of restrictions is 4 in the full set of translog and share equations. The estimated log likelihood is 374.990 for the unrestricted model and 381.781 for the restricted model. Therefore, the null hypothesis is rejected at a 5 percent level.

The final part of this section discusses effects of technological change in production. According to Solow's (1957) study, a production function $q=A(t)f(\mathbf{x})$ includes a coefficient

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[56] A function is homothetic if it is a monotonic transformation of a function that is homogeneous of degree 1.

[57] Homotheticity is equivalent to separability of the cost function in factor prices and output. If the cost function is separable, $C(W, q, t) = f(q) \cdot g(W, t)$. Thus, changes in the output does not affect factor shares. Also, homogeneity of the function is equivalent to constant returns to scale in the production: $C(W, q, t) = q \cdot g(W, t)$.

to represent a function of time A(t). Technological change is defined, in this study, as a change in productivity as time passes. Hicks' neutrality of technological change can be measured by the marginal rate of substitution (MRS) between production factors. A technology is Hick's neutral if the MRS of a factor for another factor is always constant as the ratio of amounts of factors (*i.e.*, the factor share) remains constant. If the MRS of the *i*-th factor for another factor is increasing over time with constant factor shares, the technology is called *i*-th factor-saving. On the other hand, if the MRS is decreasing, it is *i*-th factor using. To put it differently, as a ratio of factor prices is constant, the *i*-th factor share decreases, if the technology is *i*-th factor saving. Also, if the factor share increases, it is *i*-th factor-using. The factor share is constant if technological change is neutral. Thus, the technological change bias is measured by the following elasticity:

$$\epsilon_\tau = \frac{\partial S_i}{\partial t}\frac{1}{S_i} \tag{57}$$

Technological change is *i*-th factor saving if $\epsilon_\tau<0$; *i*-th factor using if $\epsilon_\tau>0$; and *i*-th factor neutral if $\epsilon_\tau=0$. Since $\partial S_i/\partial t = \beta_{it}$ in the translog equation, $\partial S_i/\partial t = \beta_{it}$, $\epsilon_\tau = \beta_{it}/S_i$.

Table 5.2.4 shows estimated elasticities of technological change bias. According to the results, the technology has developed using more labor and less land. Hypothesis of neutral technological change in chemical is not rejected at the 10 percent level of significance. These results are not consistent with the previous studies such as Kuroda (1988) and Kako (1979). Note that the former translog cost function studies, Kuroda (1988) and Kako (1979) used a linear time trend variable, which appears as logarithms of trend (ln*t*, where *t*=1,2, ···) in a translog equation. This implicitly assumes that annual growth rates of productivity declines over time. On the other hand, the model in this study, like most of the other translog studies, uses an exponential time variable for the technological progress. In the translog equation, the time trend index will be linear (t=1, 2, ···). In this case, the trend is assumed to exhibit a constant annual growth rate. Estimates in the model with linear trend are similar to those in the above case (Appendix Tables A.5.2.17).

Table 5.2.4 Estimates of Technological Change Bias

Labor	Land	Chemical	Capital
0.028 (0.014)	-0.079 (0.036)	-0.028 (0.027)	-0.046

Standard errors are in parentheses.

Conclusions

Estimation in this chapter shows that elasticities of factor demand with respect to output are large for labor and land, while they are small for chemical and capital. These estimates show that as output changes, demand for labor and land change greatly, while chemical and capital change little. Since output of Japanese agriculture is declining, the results suggest that labor and land will decrease rapidly. Also estimated partial elasticity of factor substitution shows high substitutability between chemical and labor. In Japan, relative price of labor (wage) has been increasing as labor demand for nonagricultural sector increased. If this trend continues, more labor will be replaced by chemicals in Japanese agriculture. Due to the effect of substitution of labor for chemicals in addition to effect of decreases in output on labor, labor demand will decrease significantly. Thus, output changes caused by import liberalization will change the production structure into less labor-intensive.

Estimation of bias in technological change shows that the technology has developed as using more labor. This result is probably due to increasing demand for products requiring intensive labor use in production, such as forced vegetables and horticultural products. Yet, the degree of the technological change bias is very small and almost negligible, compared to the effects of changes in factor prices or output.

On the other hand, the output elasticity chemical is small, implying that chemical demand does not decline so much when output decreases. In addition, as explained above, chemical use increase as labor price rises. These estimates imply that although chemical demand declines, chemical used per unit output will increase.

CHAPTER 6

SIMULATION FOR FACTOR ADJUSTMENT

The previous chapter estimates long-run effects of a 1 percent change in the output on factor use, assuming factor prices are constant. Although this measurement is useful for a structural analysis of production, measurement of short-run effects of output changes, along with associated changes in input prices, is often more useful for a policy analysis. This is the case for estimating how trade liberalization might change production structure in Japanese agriculture in terms of its factor use. In this chapter, simulations are carried out to explore impacts of output reductions due to the trade liberalization on factor adjustment.

6. 1 Output Path Under Trade Liberalization

There is uncertainty and about the output response path under liberalization of agricultural imports. The last GATT agreement requires each country reduce tariff rates by 36 percent on average over 6 years. Japan decided to use a minimum access option for rice imports. However, it is not known how the Japanese government will release imported rice or what kind of policy the government will implement after the period of minimum access. Also, the future demand for imported agricultural products is uncertain (*i.e.*, how consumers react to newly imported food, whether they prefer foreign food, and how fast they are adapted to these products).

Thus, since it is difficult to predict exactly what output changes will occur in the future, several different cases of potential output changes are set up for simulation. The first case assumes that output decreases by 1 percent per year, so that rates of output change are constant over time (Case I). In the second case, output declines at faster rates at the beginning and the rate of changes gradually declines (Case II).[58] This case considers a situation where greater impacts occur after a shock and then smaller, delayed impacts continue for a long term. The third and fourth cases (Case III and Case IV) represent upper and lower boundaries of the first case. The upper boundary shows the lowest possible reduction in output, so that output is reduced by 0.5 percent a year, or approximately 5 percent after 10 years. Similarly, the lower boundary shows the highest possible reduction in output, which is 2 percent a year or approximately 18 percent after 10 years. Although choice of upper and lower limits are rather arbitrary, it seems unlikely that the output path will diverge from the region between the two boundaries. A real adjustment path lies between these four lines. Output paths of these cases are presented in Figure 6.1.

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[58]In the case of geometric adjustment, a rate of decrease in output at period t is assumed to be approximated as $(1/2^{t-1}$; then it is normalized so that the output level after 10 years will be equal to the level in the first case.

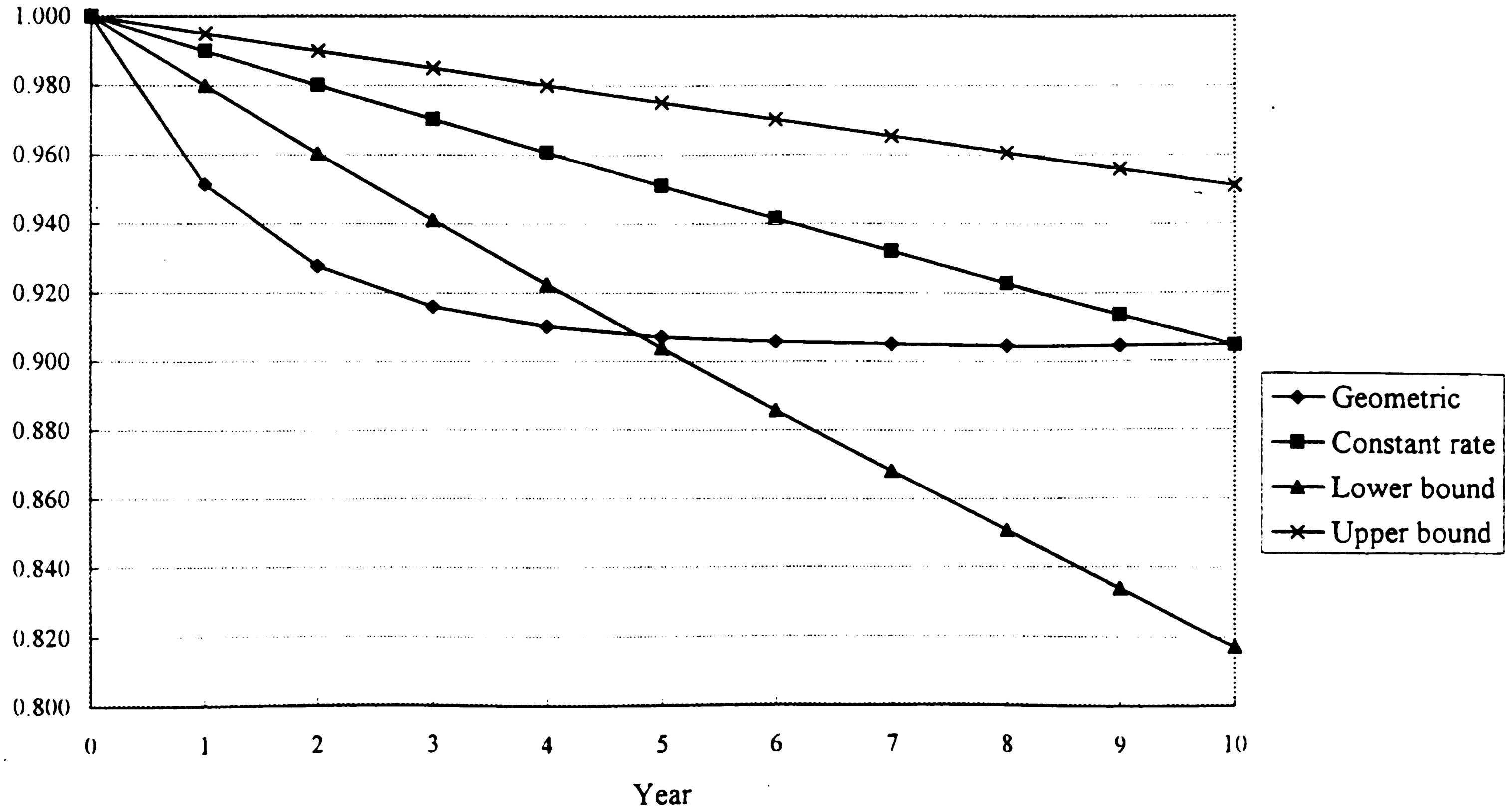

Figure 6.1 Proportion of Base Output in Year 1

6. 2 Long-Run Equilibrium Adjustment

An output elasticity of factor demand as discussed in the previous chapter, evaluates a change in factor use caused by shifting the factor demand curve when an output decreases, holding factor prices constant. However, unless factor supplies are perfectly elastic, a reduction in output will also lead to a change in factor prices. Thus, an effect of change in output on factor use is sum of effect of shifting factor demand curve and effect of changing factor demand along the demand curve.

Adjustment of factor price and factor use is evaluated by a linear approximation, a so-called "equilibrium displacement" model. Define factor demand and factor supply as

$$\begin{aligned} x &= x^d \quad \text{(factor demand)} \\ x &= x^s \quad \text{(factor supply)} \end{aligned} \tag{58}$$

By totally differentiating these, we get,

$$\begin{aligned} dx &= \frac{\partial x^d}{\partial w} dw + \frac{\partial x^d}{\partial q} dq \\ dx &= \frac{\partial x^s}{\partial w} dw \end{aligned} \tag{59}$$

Now, amount of changes in supply and demand must be equal in equilibrium, thus,

$$\frac{\partial x^d}{\partial w} \cdot w \cdot \frac{dw}{w} + \frac{\partial x^d}{\partial q} \cdot q \cdot \frac{dq}{q} = \frac{\partial x^s}{\partial w} \cdot w \cdot \frac{dw}{w} \tag{60}$$

$$\epsilon^d \frac{dw}{w} + \epsilon^q \frac{dq}{q} = \epsilon^s \frac{dw}{w} \tag{61}$$

or

$$\frac{dw}{w} = \frac{\epsilon^q}{\epsilon^s - \epsilon^d} \frac{dq}{q} \tag{62}$$

This equation represents effects of output changes on input price. Also, from this equation and the supply function, effects of output changes on factor use is given by

$$\frac{dx}{x} = \frac{\epsilon^s \epsilon^q}{\epsilon^s - \epsilon^d} \frac{dq}{q} \tag{63}$$

This procedure requires an estimated value of factor supply and demand elasticity. According to Masui's estimation (1995), the elasticity of supply of labor in rice production in Japan is 2.29. Also, in his earlier study on factor markets related to rice production (Masui, 1984), he uses assumptions that land supply elasticity is between 0.10-0.11 and chemical and capital supplies are perfectly elastic. The perfectly elastic supply of capital and chemicals are explained by the fact that most chemical and capital goods are imported and exported and manufacturing firms may have large enough capacity to increase output in the short run. Nonetheless, even though these are manufactured goods, infinite price elasticity of supply seems too large, since some materials or parts for these inputs are used for specific purposes for agriculture. For example, agricultural machinery is not used in other industry. Thus, this study assumes supply elasticities of labor, land, chemical, and capital to be 2.29, 0.10, 20, and 10, respectively.

Using the long-run price elasticities of factor demand and the output elasticities estimated in the previous chapter, elasticities of factor prices with respect to output are obtained. Estimated elasticities of the prices of labor, land, chemical, and capital with respect to output are respectively, 1.380, 1.881, 0.025, and 0.079. Long-run equilibrium factor uses associated with output paths in Cases I, II, III, and IV are presented in Figures 6.2a, 6.2b, 6.2c, and 6.2d, respectively.

Elasticities of factor demand with respect to output estimated by the equilibrium displacement model are 1.084 for labor, 0.188 for land, 0.259 for chemical, and 0.785 for capital. These output elasticities of chemical and capital are similar to the output elasticities estimated in the previous chapter, which assume constant factor prices. It is because supply elasticities of chemical and capital are large so that these prices barely change even when output changes. The output elasticity of land estimated by this model is small reflecting inelastic supply.

6.3 Dynamic Adjustment of the Factor Shares

Estimation of Dynamic Model

The previous section simulated factor use at the long-run equilibrium by assuming all factors can be adjusted instantaneously to their long-run equilibrium. However, as we discussed in the previous chapters, delay in factor adjustment may result in short-run disequilibrium. This section makes a simulation of factor adjustment using a dynamic adjustment model which allows short-run disequilibrium. Factor shares are simulated instead of factor use, because the dynamic model used in this study is based on share equations such that only shares can be estimated.

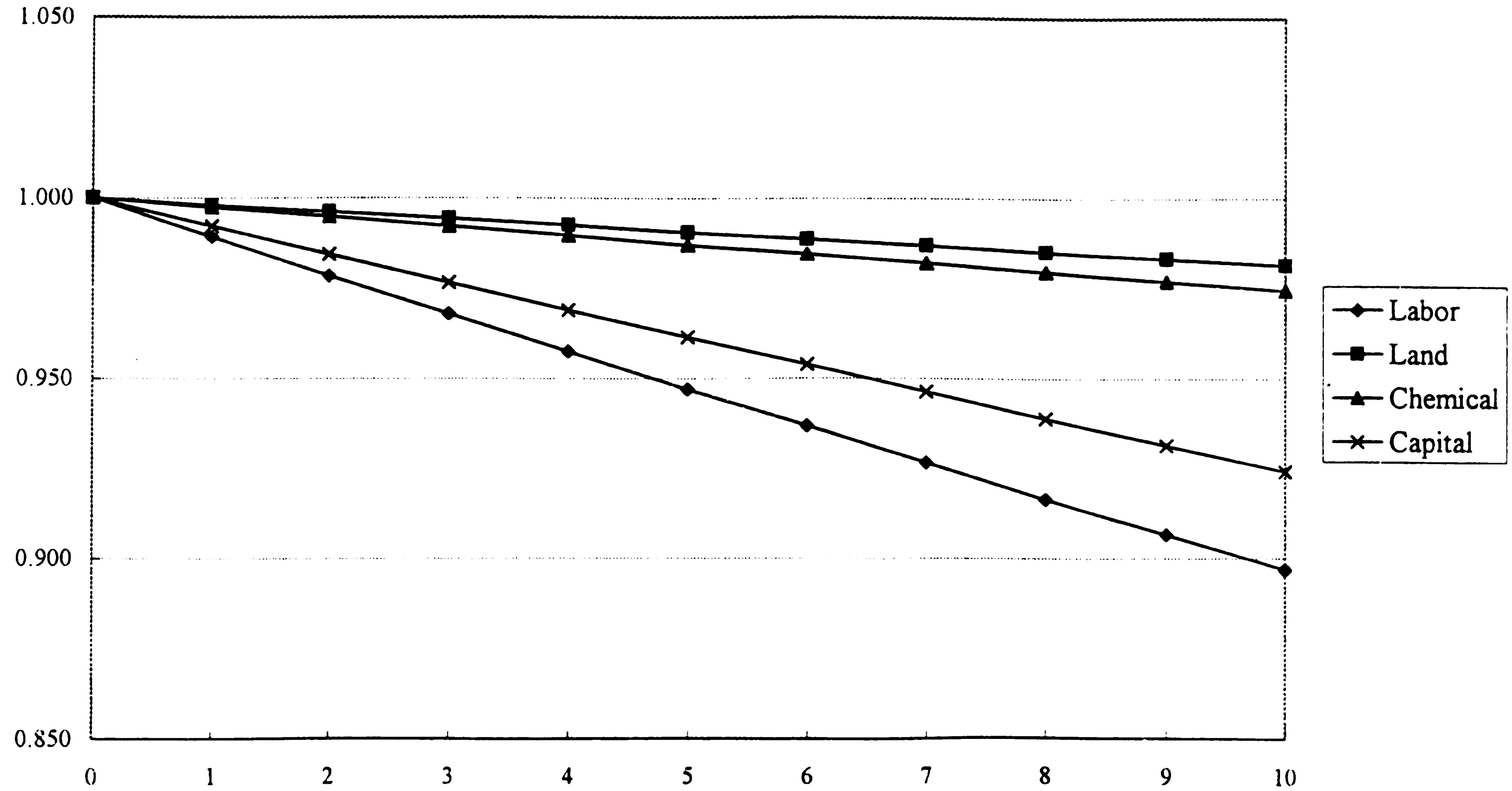

Figure 6.2a Proportion of Input Use in Year 1
Estimated by Equilibrium Displacement Model in Case I

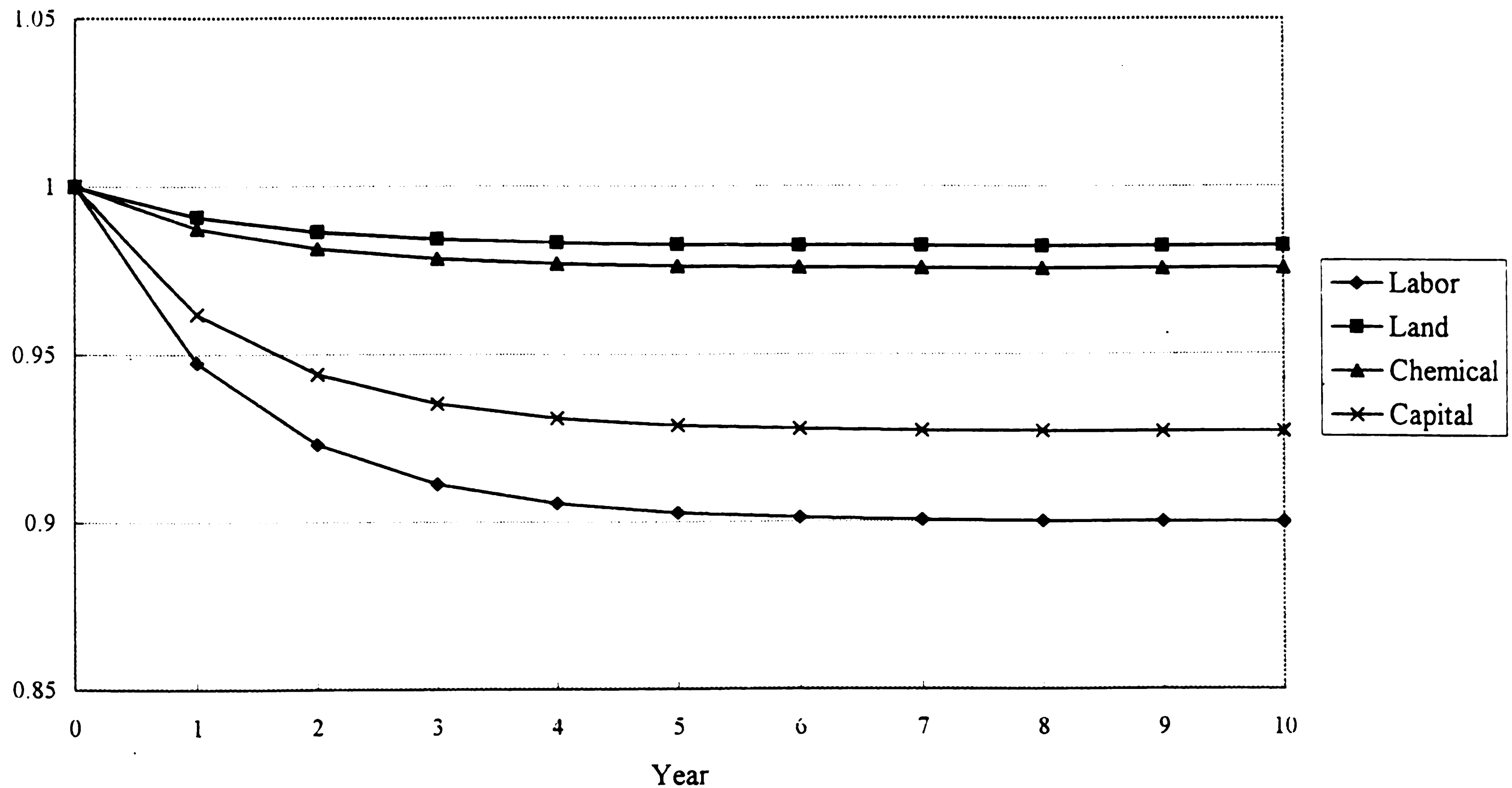

Figure 6.2b Proportion of Input Use in Year 1
Estimated by Equilibrium Displacement Model in Case II

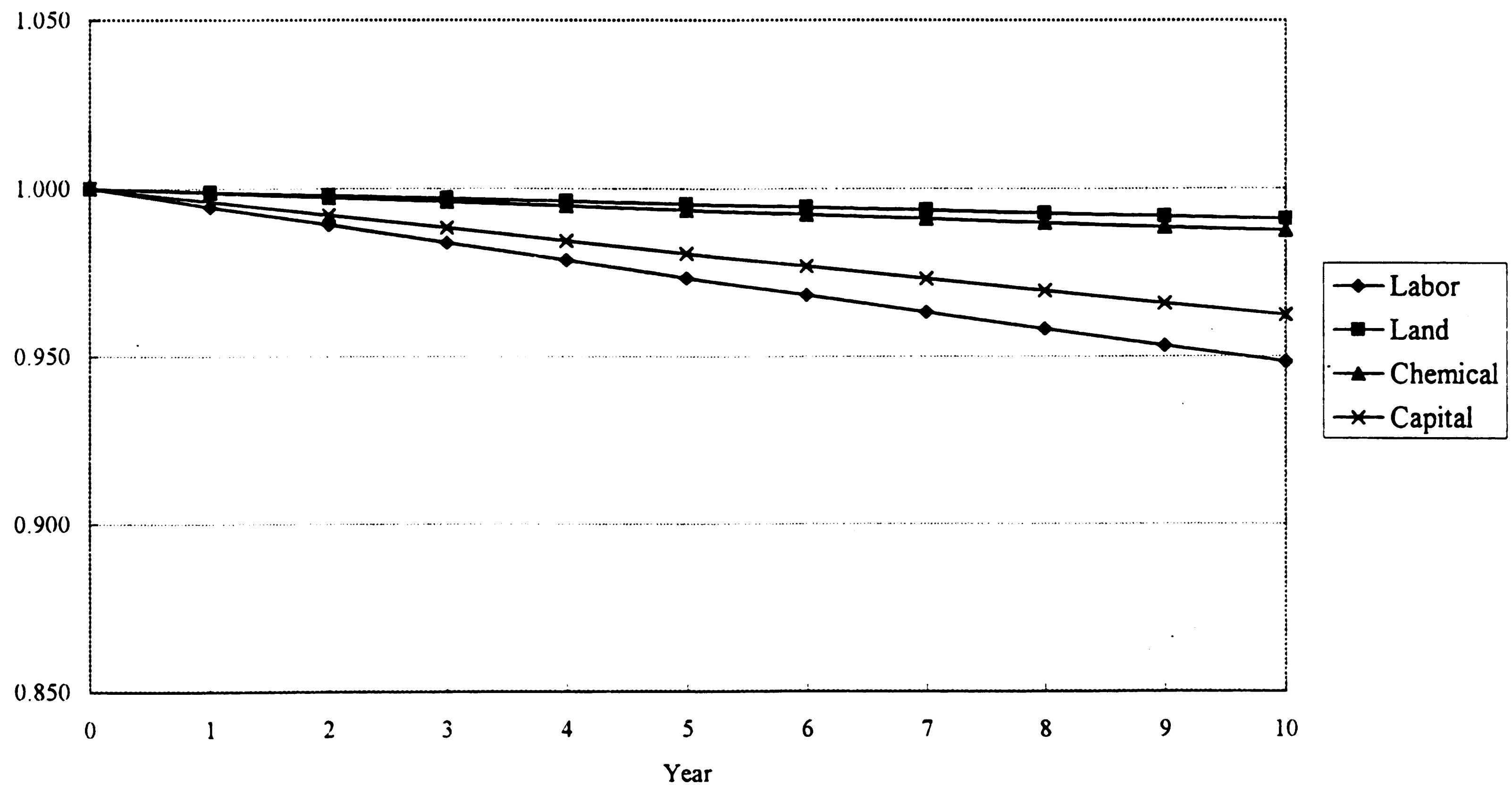

Figure 6.2c Proportion of Input Use in Year 1
Estimated by Equilibrium Displacement Model in Case III

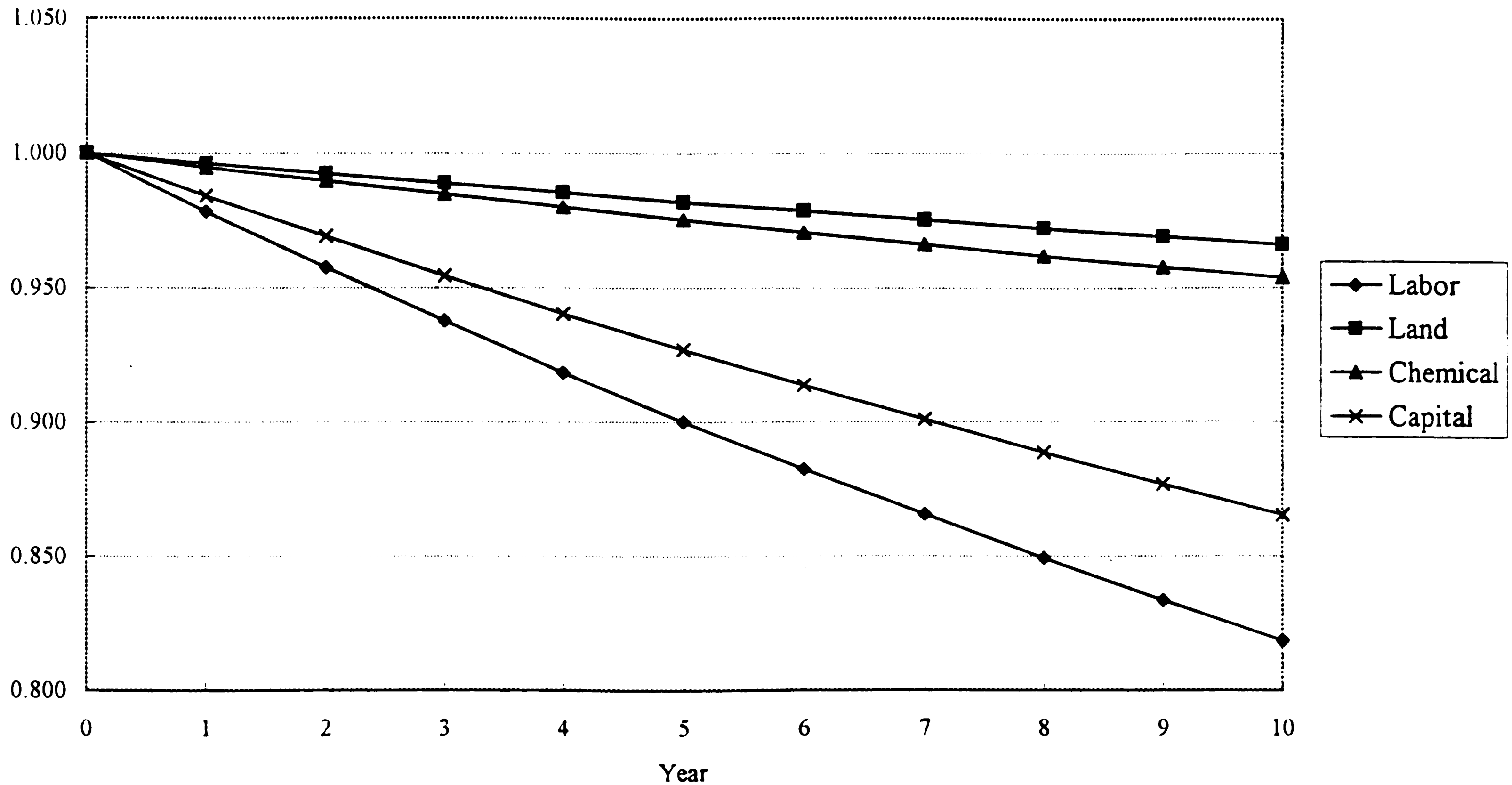

Figure 6.2d Proportion of Input Use in Year 1
Estimated by Equilibrium Displacement Model in Case IV

The simulation is based on the following dynamic model:

$$S(t) = \mathbf{B}_0 X(t) + \mathbf{B}_1 X(t-1) + \mathbf{\Phi}_1 S(t-1) + \epsilon(t) \tag{64}$$

where all variables as defined in the previous chapter. The vector B_0 represents current effects and B_1 represents lagged effects of previous changes in $X(t\text{-}1)$ on current shares.

Figures 6.3a, 6.3b, 6,3c, 6,3d show simulated factor shares for the next 10 years' period in Cases I, II, III, and IV, respectively. To present percentage changes from the initial levels, each share in the first year is set at zero. Thus, each point in graphs shows percentage increase or decrease relative to its value in the first year.

In the figures it is observed that the shares of chemical and capital increase over time, while the labor share declines. These results are basically consistent with the estimation in the previous chapter, where estimated output elasticities were larger for labor and land and smaller for chemical and capital.

Note that, although the previous analysis found that land is elastic in terms of output, this simulation suggests land changes very little. This result, however, indicate that the simulation successfully incorporates a fact that supply of land is inelastic so that the land area rarely changes in response to price changes. Although a long-run output elasticity of land estimated before is significantly large, this estimate does not represent a realistic situation for Japanese agriculture where farmland has been hardly moved. This contradiction is caused by unrealistic restriction that all factor price are fixed, imposed on output elasticities.

Simulated factor adjustment in the four cases shows distinct differences. In Case I, chemical share keep increasing at a nearly constant rate. On the other hand, in Case II, chemical share will not increase so much. The reason of this difference is probably because chemical use respond to a shock after one year so a shock in the first year are missed in both case. After the second year, increases in chemical shares are almost proportional to output changes. But, rates of output changes in Case II are much lower than rates in the case I, so that a share does not grow in Case II. The case III and Case IV show distinct adjustment path in the latter periods, although adjustment paths in the first few years are similar.

Figures also show that while the chemical increases at a nearly constant rate, the capital increases at diminishing rates over time. It implies that chemical demand responds quickly to changes in prices of the factor, while adjustment of capital input has some delayed effects. The curved path of capital adjustment shows that the adjustment is not made instantaneously.

Finally, it must be noted that cross-factor effects of demand and supply are not included in this analysis. As the factor demand curve shifts down due to decrease in output, the factor supply and demand curves may shift more or less than the primary effect due to secondary effects in the factor market. For example, if there are significant substitutional effects in a demand, estimated factor levels without including the secondary effects will possibly be underestimated. However, such effects are considered to be sufficiently small for taking a general view of changes in the factor shares in the simulation.

6.4 Implication for Trade Liberalization

Simulation in this chapter show that trade liberalization has a significant impact on the structure of Japanese agriculture, especially for labor use. This significant change in labor demand is due to a large output elasticity and a large elasticity of labor supply. The high output elasticity implies high absorption effects of labor. In response to output changes, labor demand also changes by a large degree. Even though labor demand decreases significantly, wage rates will not be decreased much because labor supply is elastic enough to change labor supplied, in response to a small change in wages.

Output elasticity of labor estimated in the long-run equilibrium adjustment model suggests that a 1 percent decline in output results in a 1.1 percent decline in labor, which also implies a slight increase in labor productivity (*i.e.*, output per labor). As producers reduce costs of production by reducing labor, output per unit labor hour would even increase. Current part-time farmers will spend more hours in off-farm jobs. Promotion of part-time farming has never turned out to be a serious consequence in rural areas. Improving labor productivity is beneficial to rural areas where labor shortage appear rather problematic.

Also, some people suggest that trade liberalization would cause various environmental problems due to a decrease in land areas, including deteriorating rural landscape, a decrease in water preserving function related to rice production.[59] This situation is also not likely to occur because farmland area would change very little. Even though trade liberalization leads to decline in an output level in Japan, almost the same area of land will be used in agriculture.

Another consequence of import liberalization is a decrease in yield (*i.e.*, output per a unit area of land), which occurs because output would decline but land area would hardly change. As yield decreases, output per unit use of machinery will fall, since use of machinery, such as reaping or planting machines, often corresponds to land area. Output elasticity of a capital use implies that capital productivity (*i.e.*, output per unit capital) decreases by 0.2 percent as output declines by 1 percent.

Output elasticity of chemicals implies that chemical use per unit output rises by 0.7

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[59]An example of this argument is in Morishima (1991)

percent as output declines 1 percent. This may result in increasing chemical residues on agricultural products. Production costs are reduced by cutting labor and capital inputs, not by reducing chemicals. Then, the amount of chemical applied per unit output would increase as output per area of land declines. However, estimated output elasticities of land and chemical are both small, which implies that chemical use per land would remain relatively constant. Thus, the overall environmental impact of changes in chemical use is ambiguous.

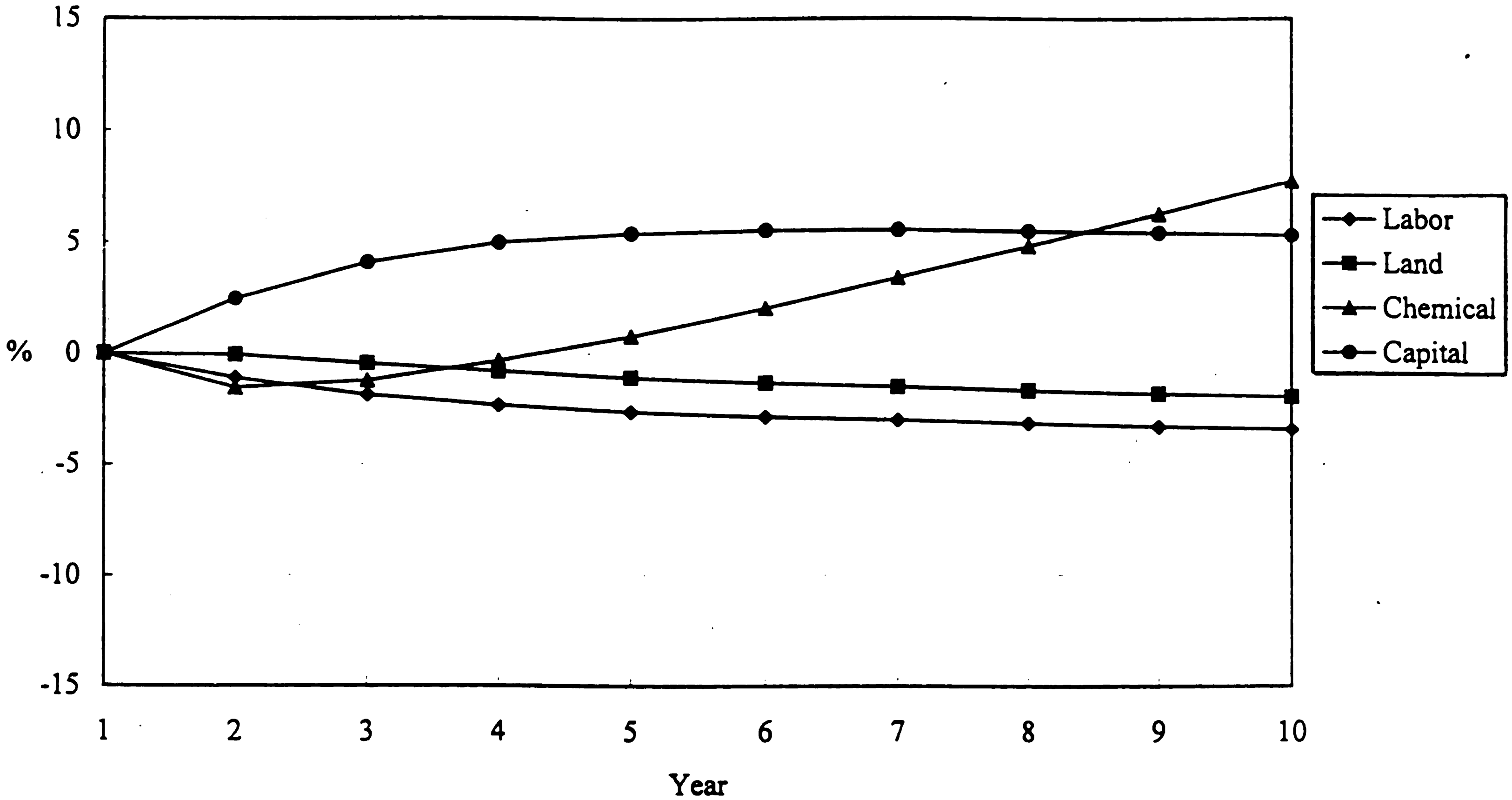

Figure 6.3a Proportion of Input Share in Year 1
Estimated by Dynamic Model in Case I

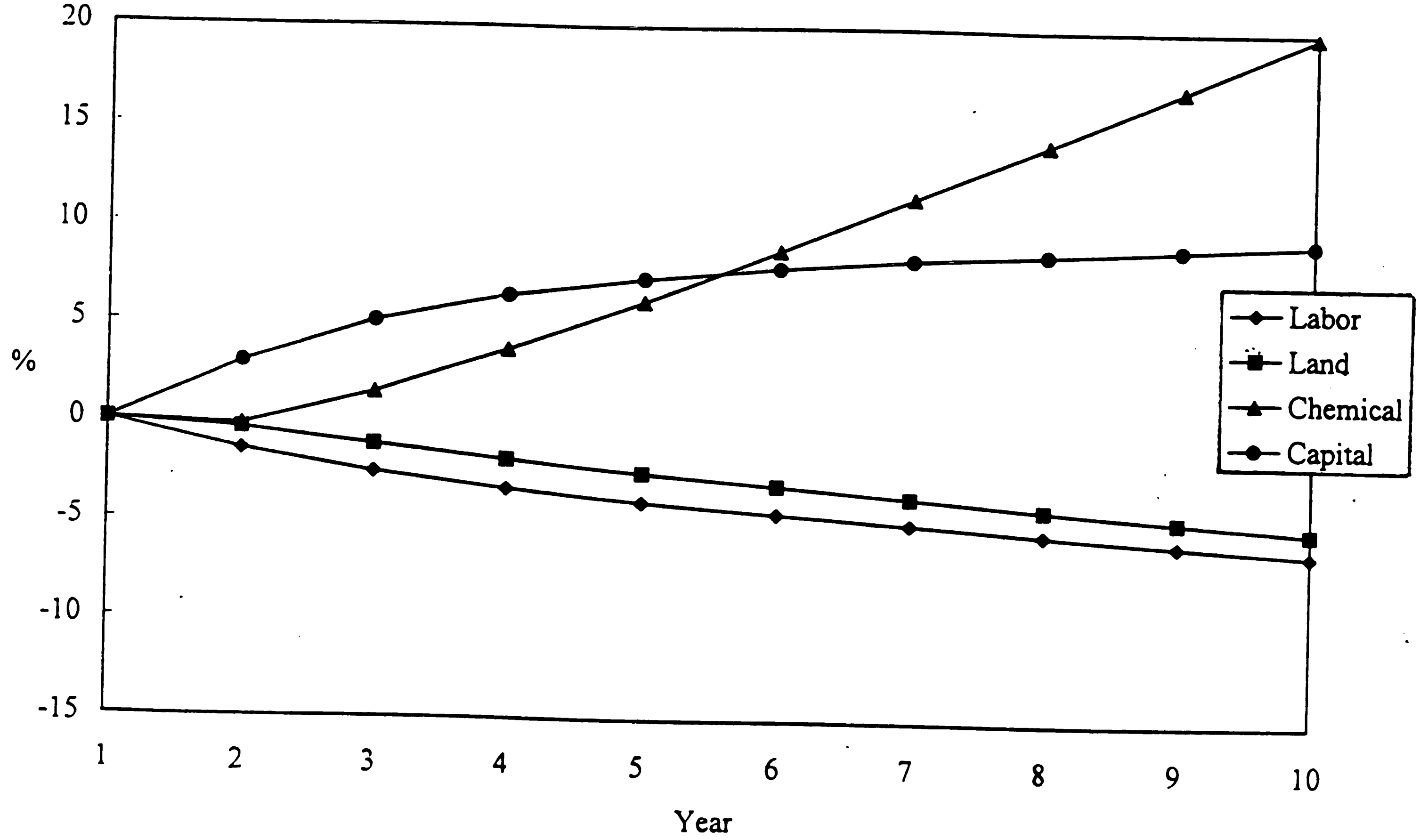

Figure 6.3d Proportion of Input Share in Year 1
Estimated by Dynamic Model in Case IV

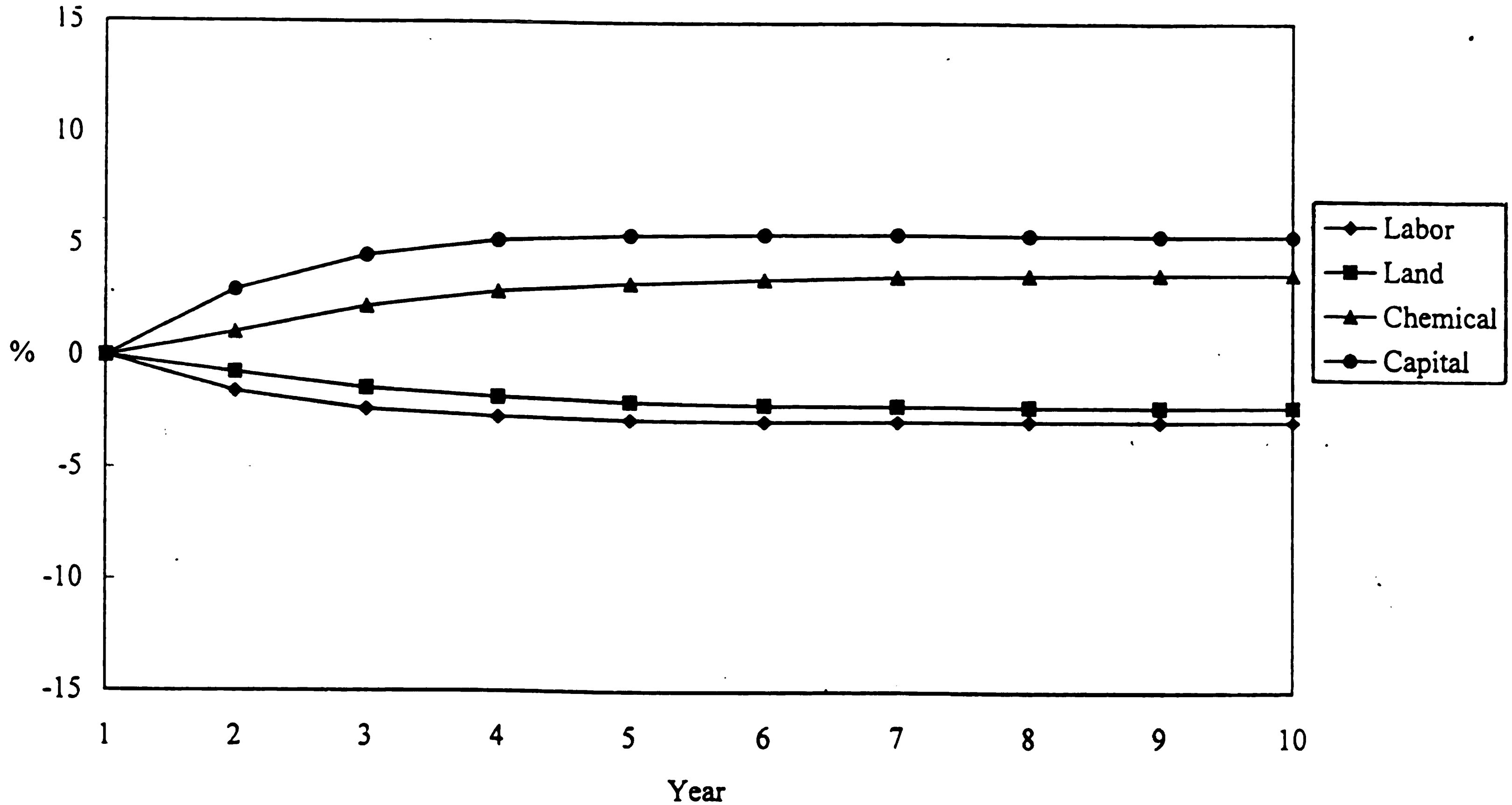

Figure 6.3b Proportion of Input Share in Year 1
Estimated by Dynamic Model in Case II

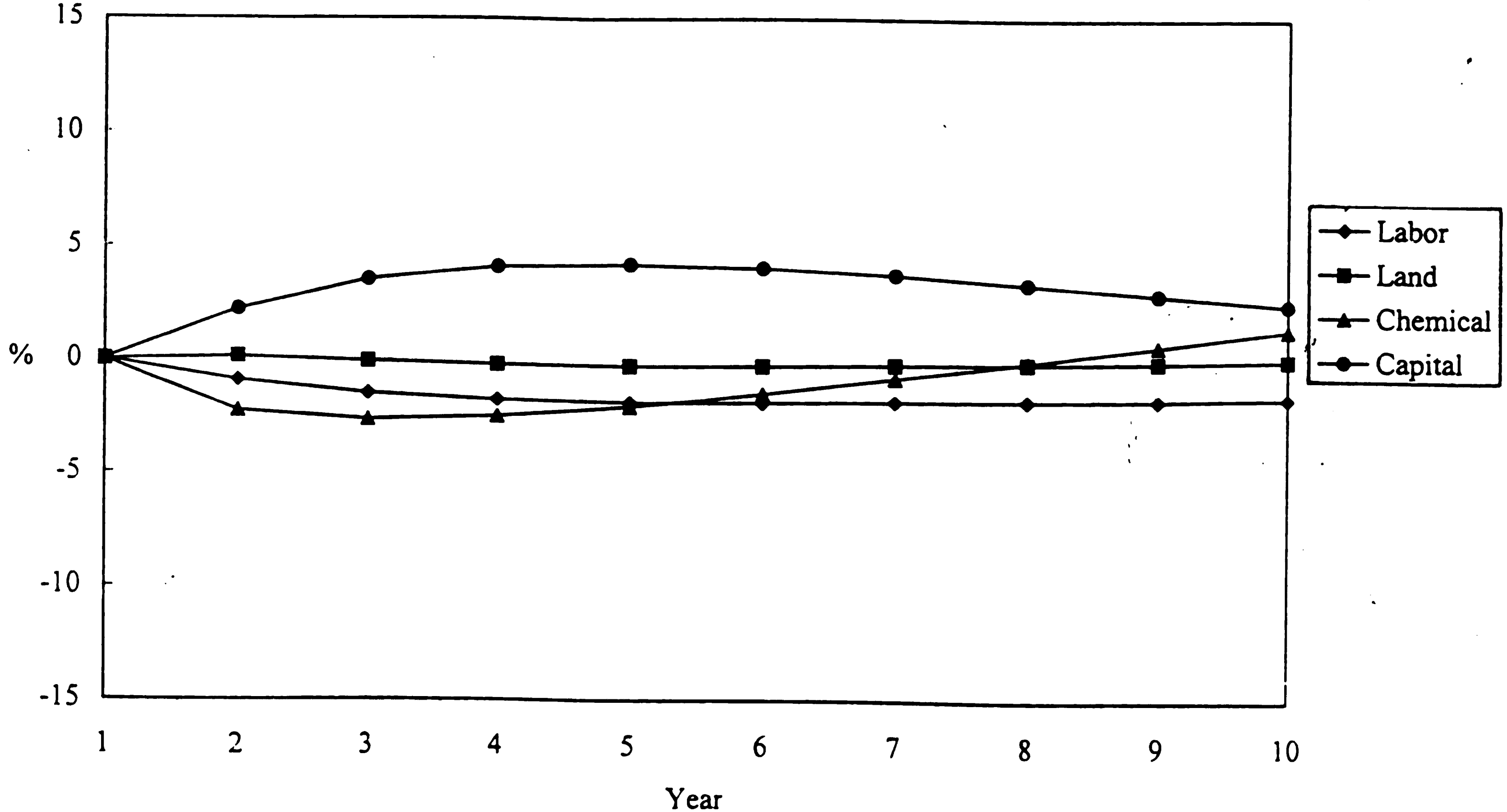

Figure 6.3c Proportion of Input Share in Year 1
Estimated by Dynamic Model in Case III

CHAPTER 7

SUMMARY AND CONCLUSIONS

This study has explored the structure of agricultural production in Japan using a dynamic cost function model. The primary focus of this study is estimation of elasticities of factor demand with respect to output. A dynamic model is used because it is realistic to assume that factors are not adjusted instantaneously. The adjustment may be delayed due to rigidity in factor movement caused by high costs of adjustment, delay in obtaining necessary economic information, farmers' custom about production practice, and institutional problems that hinder quick adjustment. For example, changing occupation often requires costs of searching a new job, obtaining a new skills, and moving residence, etc. Also, adjustment of capital inputs often requires large-scale investment on machinery and construction. Thus, changes in the output level possibly create a short-run disequilibrium although it is assumed that a long-run equilibrium is achieved over time. Since a major objective of this study includes estimating long-run adjustment, we applied an econometric model that allows short-run disequilibrium but still captures long-run relationships.

The econometric model used in this study, called the flexible dynamic model, is derived from an ARX model of a system of share equations derived from a translog cost function. The translog model has flexible properties in terms of factor substitution and nonhomothetic production process. Static specification of a translog model, which was applied to aggregate production studies of Japanese agriculture in the past, is statistically rejected in favor of the dynamic flexible model. Thus, results in the past studies may be biased and therefore a dynamic specification is required when instantaneous factor adjustment cannot be assumed.

This study derived an estimation method to measure a long-run elasticity of factor demand with respect to output. The elasticity measures proportional changes in factor demand with respect to changes in output along an expansion path. In the measurement, factor prices are fixed while all factor levels are allowed to be changed. Thus, a concept of output elasticity used in this study is similar to measurement of bias in technological change which evaluates shifting in an isoquant holding the factor prices constant.

The estimated output elasticities of labor and land are relatively large, while the output elasticities of chemical and capital use are relatively small. The estimation results also suggest that shares of labor and land change greatly in response to changes in output, but shares of chemical and capital change just a little. Also, as output decreases, labor required to produce a unit of output decreases, while chemical and capital use per unit of output increases. Simulation of factor share adjustment confirms that chemical share grows more than the other factors

Estimated Allan's partial elasticities of factor substitution show that most factors are substitutes for each other. Large values of the elasticity of substitution between labor and the other factors imply that labor has high substitutability for the other factors. The estimated elasticities of substitution are not constant across the inputs, supporting the flexible dynamic model against other dynamic models which are more restrictive in terms of factor substitution.

Estimated elasticities of factor demand with respect to prices of the factors also vary among the pairs. In terms of own price elasticities of factor demand, labor is as elastic as other factors. Elastic demand for land in terms of price and output implies that land can be adjusted flexibly. However, this finding is not consistent with the real situation of Japanese agriculture, where little transfer of land has been observed in the past. It shows a major problem for elasticity measurement.

The model used in this analysis assumes other economic factors, such as input prices, are constant over time, which means input supply elasticities are all perfectly elastic. However, even though factor demand changes greatly, factor use hardly changes if input supply is inelastic. This is a case of land adjustment. Since the land supply is considered as very inelastic, the land area hardly changes, while price of land stays at the initial level. In the very long-run, a factor supply elasticity may be assumed to be significantly large, then our estimation of the elasticity in a long-run equilibrium estimated by the flexible model can be justified.

This thesis has also dealt with the issue of short-run factor adjustment in the simulation. Each factor price is associated with output changes, so that paths of factor shares are expressed as a function of an output path.

The simulation shows that as output decreases, the shares of chemical and capital will rise, while the share of labor declines. Land share changes little. It is a realistic outcome for Japanese agriculture. Estimation of bias in technological changes has found that production is land-saving, but other effects are not conclusive. Because of rapid economic development during the 1960s and 1970s and changing demand for food products, the technology in agriculture had changed at the middle of the observation period. Thus, technological change bias was hardly captured in the estimation.[60]

Estimated output elasticities of factor demand show that, due to output decrease caused by trade liberalization, more chemical and capital will be used to produce a unit of output in Japanese agriculture, although the total amounts of these inputs are reduced. Production using more chemicals per unit output may worsen problems related to chemical residues on domestic agricultural products. Also, since the output elasticity of chemicals is almost the same as the output elasticity of land, average use of chemical per hectare of farmland will not reduced even though the total output decreases. Currently, amount of chemical used per hectare is very high in Japan, the high input agricultural practice will remain.[61]

Also, this study has found that labor requirements is reduced significantly. As long as the current labor shortage continues, the decrease in labor requirement will not have serious consequences for the rural sector. The majority of farm workers in Japan are elderly people and few successors are found in the rural areas. The labor shortage will lead to a decrease in the rural population, which could deteriorate rural economies due to lack of funding for public services and decrease in business opportunities. Since the majority of Japanese farmers have income sources in the non-farm sector, the decrease in working hours in farming would give them opportunities to allocate more hours in their non-farming works. Thus, large scale unemployment in the rural sector is not likely to occur in most rural areas.

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[60]It may be preferred to use a model with a variable parameter to represent shifting bias in technological change over time.

[61]Although more detailed data is required to explore relationships between chemical use in agricultural production and water and soil contamination, and relationship between chemical contamination in water systems and their effects on human body, the high level of chemical use per hectare is a major source of chemical contamination at farming areas in Japan.

Limitation and Extension of This Study

This study relaxes restrictions maintained in most previous models, such as instantaneous adjustment of factors and constant elasticities of factor substitution. However, there are several restrictions in the analysis of this study. First, due to small size of the sample used in the estimation, the tests of unit roots have limited power to reject the null hypothesis. The hypotheses of unit roots in series of some factor shares are not rejected, although shares are not likely to have unit roots since they are bounded on values of zero and one. However, it is difficult to collect a larger sample of data than that used in this study, since data of agricultural production are annual and reliable data are available only after the World War II.

Also, the estimation in this study provides only rough information about changes in factor use since the variables in the model represent highly aggregate inputs and output. For example, 'chemical' input in the model includes pesticides and fertilizers. Although both pesticides and fertilizers affect the environment negatively, these two types of chemical often give different impacts on the environment. This study can only show how much aggregate demand for chemical increases or decreases as output changes, but more specific implications for the environment is not provided. Further dissagregating the model would be more useful for policy analysis. However, increasing the number of variables in the model sacrifices the degrees of freedom significantly.

This study implements the simulation of short-run factor adjustment in terms of factor shares, instead of factor use. Since the dynamic model in this study is based on share equations, which are derived from the static translog function, the model only takes the shares as dependent variables. Thus, the simulation does not show absolute degrees of the changes, but just illustrates relative changes in terms of the total cost. On the other hand, the first simulation in the previous chapter (long-run equilibrium adjustment) shows absolute levels of factor use. However, it does not represent short-run disequilibrium in the factor adjustment, since all factors are assumed to be at the long-run equilibrium in the model.

The analytical method used in this thesis could be applied to other regions in the world. Although this study has dealt with the case of an agricultural sector whose output is decreasing, a similar analysis can be made for a sector with expanding output. In a country exporting agricultural products, for example, trade liberalization would lead to an increase in domestic production, then the country may be concerned about short-run and long-run effects of export policies on domestic employment situation, or inputs that might have negative impacts on the environment. Models applied in this study will provide useful information about how production structure might be changed due to changes in output.

APPENDIX

APPENDIX

Table A.4.2.1 Phillips-Perron Tests for Unit Roots in Individual Variables in Dickey Fuller Equations with Constants and Time Trend

	W_L	W_D	W_{CH}	W_K	Q	S_L	S_D	S_{CH}	S_K
C	0.097263	0.181177	-0.006320	0.053881	0.082609	0.085046	0.003395	0.142787	-1.729205
	(2.319)	(3.655)	(-0.233)	(2.971)	(2.825)	(2.243)	(0.609)	(3.667)	(2.103)
t	0.005130	-0.002889	0.002126	0.000628	0.000344	0.000487	0.001650	-0.002462	-0.000680
	(0.650)	(-0.377)	(1.221)	(0.205)	(0.295)	(1.334)	(2.875)	(-3.506)	(-1.903)
ρ	-0.062126	-0.008650	-0.065025	-0.029457	-0.209008	-0.241347	-0.337237	-0.576124	-0.111154
	(-0.821)	(-0.135)	(-1.229)	(-0.4670	(-2.305)	(-2.575)	(-2.746)	(-3.838)	(-1.640)
s^2	0.011205	0.022444	0.004680	0.002456	0.004671	0.000756	0.000274	0.000357	0.000730
γ_0	0.010007	0.021173	0.004306	0.002422	0.003489	0.000683	0.000267	0.000292	0.000714
γ_1	0.002727	0.000586	0.002368	0.001225	-0.000400	0.000024	0.000031	-0.000004	0.000085
γ_2	0.000839	-0.003484	0.000906	0.000117	-0.000864	-0.000147	-0.000039	-0.000043	-0.000049
$Z(\rho)$	-3.567	-0.056	-3.764	-2.424	-7.322	-9.096	-13.578	-21.948	-4.681
$Z(t)$	-1.051	-0.019	-1.431	-0.804	-2.200	-2.512	-2.723	-3.745	-1.658
γ_0	0.008988	0.021707	0.004502	0.002302	0.002988	0.000454	0.000280	0.000292	0.000668
γ_1	0.003113	0.000651	0.002506	0.001279	-0.000389	-0.000002	0.000036	-0.000004	0.000070
γ_2	0.001908	-0.003020	0.000930	0.000217	0.000020	-0.000049	-0.000043	-0.000015	-0.000050
γ_3	0.002872	0.010272	0.000660	0.000183	-0.000374	0.000100	-0.000033	0.000048	-0.000170
γ_4	-0.000838	0.000508	0.000137	-0.000003	-0.000402	0.000025	-0.000036	-0.000010	-0.000043
$Z(\rho)$	-6.509	-1.258	-5.536	-4.541	-7.003	-10.172	-12.147	-24.142	-4.019
$Z(t)$	-1.579	-0.429	-1.712	-1.252	-2.212	-2.589	-2.589	-3.867	-1.561
γ_0	0.006841	0.021978	0.004729	0.002433	0.002976	0.000452	0.000452	0.000300	0.000699
γ_1	0.004031	0.000866	0.002615	0.001326	-0.000006	0.000065	0.000065	0.000004	0.000093
γ_2	0.003845	-0.002571	0.000992	0.000245	-0.000060	-0.000015	-0.000015	-0.000012	-0.000047
γ_3	0.001571	0.010137	0.000687	0.000207	-0.000864	0.000035	0.000035	0.000028	-0.000200
γ_4	-0.001467	0.000375	0.000267	-0.000011	-0.000378	0.000041	0.000041	-0.000030	-0.000034
γ_5	-0.001747	-0.002928	0.000402	-0.000149	-0.000029	-0.000038	-0.000038	0.000015	-0.000131
γ_6	-0.002479	0.003850	0.000610	0.000306	-0.000496	-0.000134	-0.000134	-0.000038	-0.000067
$Z(\rho)$	-7.367	-1.769	-6.345	-5.088	-6.251	-10.925	-18.706	-23.295	-3.178
$Z(t)$	-1.729	-0.569	-1.827	-1.340	-2.214	-2.631	-3.152	-3.819	-1.430

Note: t-statistics are in parentheses; C: constant; t: coefficient of the time trend variable; γ:autoregressive coefficient of the OLS with constant and trend variables; γ_j: covariance of the residuals; s^2:variance of the residuals of regression; $Z(\rho)$:Phillips-Perron statistic of the coefficient with p-th order lag truncation; Z(t):Phillips-Perron statistic of the *t* value of with p-th order lag truncation. Critical values for $Z(\rho)$ and Z(t) at 5% levels are 19.80 and 3.50 (T=50).

Table A.4.2.2 Dickey-Fuller Tests of the Residual from Cointegrating Regression

	ε	ε	ε
ρ	-0.438202 (-3.27084)	-0.438641 (-3.22891)	-0.449213 (-3.28002)
constant		-0.001288 (-0.072768)	-0.030573 (-0.781746)
trend			0.0012988 (0.840661)

Note: t-statistics are in parentheses; ε is the OLS residuals from the cointegrating regression of L on D, CH, K, and Q; ρ is the coefficient of the lagged residual.

Table A.4.2.3 Phillips-Perron Tests for Residuals from Cointegration among S_i, L, D, CH, K, and Q

	S_L	S_D	S_{CH}	S_K
ρ	-0.307733 -2.672460	-0.288276 -2.411540	-0.647168 -4.318820	-0.224885 -2.155330
γ_0	0.000535	0.000381	0.000254	0.000097
γ_1	0.000543	0.000408	0.000277	0.001069
γ_2	0.000068	0.000087	0.000008	0.000251
γ_3	-0.000090	-0.000039	-0.000025	-0.000104
γ_4	0.000070	-0.000061	0.000026	-0.000200
s^2	-0.000016	-0.000050	-0.000022	-0.000112
Z(ρ)	-13.662	-11.824	-22.295	-15.930
Z(ρ)	-2.767	-2.357	-4.159	-2.545

Note: t-statistics are in parentheses; C: constant; t: coefficient of the time trend variable; γ:autoregressive coefficient of the OLS with constant and trend variables; γ_j: covariance of the residuals; s^2:variance of the residuals of regression; Z(ρ):Phillips-Perron statistic of the coefficient with p-th order lag truncation; Z(t):Phillips-Perron statistic of the *t* value of with p-th order lag truncation. Critical values for Z(ρ) and Z(t) at 5% levels are -42.5 and -4.74 (T=50).

Table A.5.1.1 Hessian Matrices of the Flexible Model

	No Restriction				Symmetric Restrictions				Homothetic Restrictions			
	L	D	C	K	L	D	C	K	L	D	C	K
L	-0.244	-0.005	0.481	-0.327	-0.270	0.030	0.125	0.284	-0.260	0.029	0.118	0.317
D	0.041	-0.039	0.191	-0.351	0.030	-0.021	0.021	-0.061	0.029	-0.030	0.005	0.047
C	0.126	0.018	-0.161	-0.003	0.125	0.021	-0.180	0.026	0.118	0.005	-0.193	0.172
K	0.076	0.026	-0.511	0.681	0.115	-0.029	0.034	-0.249	0.112	-0.004	0.069	-0.535

L, D, C, and K are respectively variables for prices of labor, land, chemical, and capital

Table A.5.1.2 Hessian Matrices of the Linear Dynamic Model

	No Restriction				Symmetric Restrictions				Homothetic Restrictions			
	L	D	C	K	L	D	C	K	L	D	C	K
L	-0.238	0.004	0.138	-0.220	-0.262	0.019	0.136	1.066	-0.272	-0.043	0.126	0.221
D	0.025	-0.207	0.095	-0.155	0.019	-0.036	0.009	0.007	-0.043	-0.041	0.012	0.054
C	0.120	0.018	-0.212	0.080	0.136	0.009	-0.102	-0.044	0.126	0.012	-0.015	-0.163
K	0.094	0.185	-0.242	0.294	0.107	0.007	-0.044	-0.006	0.221	0.054	-0.163	-0.113

Note: The linear dynamic model refers to the linear model transformed from the original flexible model. L, D, C, and K are respectively variables for prices of labor, land, chemical, and capital

Table A.5.1.3 Hessian Matrices of the Static Model

	No Restriction				Symmetric Restrictions				Homothetic Restrictions			
	L	D	C	K	L	D	C	K	L	D	C	K
L	-0.224	-0.013	0.449	-0.343	-0.180	0.007	0.108	0.258	-0.161	0.033	0.087	0.041
D	-0.026	-0.017	0.110	-0.168	0.007	0.007	0.041	-0.078	0.033	-0.033	0.006	-0.006
C	0.087	0.016	-0.194	0.101	0.108	0.041	-0.098	-0.075	0.087	0.006	-0.130	0.036
K	0.163	0.014	-0.364	0.410	0.066	-0.054	-0.050	-0.105	0.041	-0.006	0.036	-0.072

Note: L, D, C, and K are respectively variables for prices of labor, land, chemical, and capital

Table A.5.1.4 Eigen Vectors of Hessian Matrices

Flexible Model			Linear Dynamic Model			Static Model		
No Restriction	Sym -metric	Symmetric Homothet.	No Restriction	Sym -metric	Symmetric Homothet.	No Restriction	Sym -metric	Symmetric Homothet.
-0.77965	-0.56430	-0.75613	0.43867	-0.56430	-0.43088	-0.76833	0.25437	0.28365
0.94277	-0.21937	-0.31984	-0.44264	-0.21937	-0.17549	0.61405	-0.19306	-0.22674
0.19082	0.07179	0.10110	-0.10066	0.07179	-0.08335	0.16551	-0.08882	-0.09378
-0.11694	-0.00819	-0.04313	-0.25903	-0.00812	-0.03437	-0.03623	-0.06049	-0.04412

Note: The linear dynamic model refers to the linear model transformed from the original flexible model

Table A.5.2.1 Parameter Estimates of Flexible Model

	Unrestricted		Symmetry		Homothetic		Symmetry & Homothetic	
	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error
β_L	0.3962	0.0256	0.3480	0.0757	0.3827	0.0348	0.3605	0.0662
β_{LL}	0.0059	0.0661	-0.0202	0.1145	-0.0193	0.0794	0.0392	0.1139
β_{LD}	-0.0244	0.0296	0.0101	0.0445	-0.0172	0.0404	0.0242	0.0463
β_{LC}	0.3672	0.1056	0.0117	0.0371	0.2870	0.1063	0.0286	0.0382
β_{LK}	-0.4436	0.2060	0.1681	0.2678	-0.2505	n.a.	-0.0920	n.a.
β_{LQ}	0.1446	0.1066	-0.1978	0.1620	0.0720	0.1247	-0.2087	0.1541
β_{LT}	0.0129	0.0043	-0.0025	0.0079	0.0090	0.0042	0.0011	0.0063
β_D	0.0203	0.0163	-0.0032	0.0344	-0.0020	0.0295	-0.0055	0.0383
β_{DL}	0.0219	0.0421	0.0101	0.0445	-0.0200	0.0672	0.0242	0.0463
β_{DD}	0.0000	0.0189	0.0180	0.0229	0.0118	0.0342	0.0093	0.0293
β_{DC}	0.1814	0.0673	0.0113	0.0203	0.0481	0.0899	0.0001	0.0193
β_{DK}	-0.3611	0.1313	-0.0714	0.1193	-0.0399	n.a.	-0.0336	n.a.
β_{DQ}	0.0929	0.0680	-0.0734	0.0748	-0.0278	0.1054	-0.0787	0.0880
β_{DT}	0.0137	0.0028	0.0062	0.0035	0.0071	0.0035	0.0046	0.0031
β_C	0.2637	0.0142	0.2609	0.0232	0.2608	0.0143	0.2625	0.0174
β_{CL}	0.0124	0.0367	0.0117	0.0371	0.0070	0.0326	0.0286	0.0382
β_{CD}	0.0081	0.0164	0.0113	0.0203	0.0097	0.0166	0.0001	0.0193
β_{CC}	0.0195	0.0586	0.0008	0.1166	0.0022	0.0436	0.0150	0.0542
β_{CK}	-0.0605	0.1144	-0.0312	0.2110	-0.0188	n.a.	-0.0437	n.a.
β_{CQ}	-0.1157	0.0592	-0.1358	0.1188	-0.1314	0.0511	-0.1165	0.0703
β_{CT}	-0.0031	0.0024	-0.0040	0.0053	-0.0040	0.0017	-0.0043	0.0023
β_K	0.3198	n.a.	0.3944	n.a.	0.3585	n.a.	0.3825	n.a.
β_{KL}	-0.0402	n.a.	-0.0016	n.a.	0.0323	n.a.	-0.0920	n.a.
β_{KD}	0.0163	n.a.	-0.0394	n.a.	-0.0043	n.a.	-0.0336	n.a.
β_{KC}	-0.5681	n.a.	-0.0238	n.a.	-0.3373	n.a.	-0.0437	n.a.
β_{KK}	0.8652	n.a.	-0.0655	n.a.	0.3092	n.a.	0.1693	n.a.
β_{KQ}	-0.1218	n.a.	0.4070	n.a.	0.0872	n.a.	0.4038	n.a.
β_{KT}	-0.0235	n.a.	0.0003	n.a.	-0.0121	n.a.	-0.0014	n.a.
α_{11}	0.4865	0.2326	0.1667	0.1464	0.3131	0.1720	0.1463	0.1414
α_{12}	0.2245	0.2230	0.1153	0.2153	0.1243	0.2061	0.1850	0.1895
α_{13}	-0.2395	0.2276	-0.4259	0.2102	-0.3438	0.2095	-0.4216	0.2108
α_{21}	0.0137	0.1653	-0.1385	0.1285	-0.1811	0.1248	-0.1448	0.1100
α_{22}	0.5788	0.1585	0.5277	0.1548	0.4663	0.1495	0.4425	0.1437
α_{23}	-0.3155	0.1618	-0.4056	0.1520	-0.4326	0.1520	-0.4221	0.1482
α_{31}	-0.0784	0.1812	-0.0426	0.1706	-0.0731	0.1321	-0.0091	0.1285
α_{32}	-0.0640	0.1738	-0.0501	0.1736	-0.0609	0.1583	-0.1227	0.1560
α_{33}	0.7406	0.1773	0.7587	0.1745	0.7438	0.1609	0.7502	0.1622

Note: "n. a." refers to the value is not available.

Table A.5.2.1 (cont'd)

	Unrestricted		Symmetry		Homothetic		Symmetry & Homothetic	
	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error
γ_{12}	0.0837	0.0478	0.0657	0.0471	0.0653	0.0453	0.0741	0.0452
γ_{13}	-0.0051	0.0260	-0.0031	0.0248	-0.0011	0.0261	-0.0045	0.0253
γ_{14}	0.1828	0.1218	0.0178	0.0837	0.0804	0.0785	0.0266	0.0741
γ_{15}	-0.2912	0.1239	-0.1663	0.1081	-0.2051	0.0968	-0.1948	0.0991
γ_{16}	0.1496	0.0554	0.1200	0.0542	0.1361	0.0548	0.1128	0.0543
γ_{22}	-0.0274	0.0340	-0.0354	0.0333	-0.0482	0.0329	-0.0479	0.0319
γ_{23}	0.0133	0.0185	0.0144	0.0182	0.0178	0.0189	0.0174	0.0186
γ_{24}	0.1478	0.0866	0.0697	0.0690	0.0327	0.0570	0.0440	0.0539
γ_{25}	-0.1583	0.0880	-0.0999	0.0798	-0.0616	0.0702	-0.0620	0.0700
γ_{26}	0.0546	0.0394	0.0403	0.0387	0.0394	0.0397	0.0447	0.0390
γ_{32}	-0.0006	0.0372	0.0027	0.0369	0.0000	0.0348	0.0047	0.0351
γ_{33}	-0.0009	0.0202	-0.0009	0.0201	-0.0010	0.0200	-0.0040	0.0201
γ_{34}	-0.0781	0.0949	-0.0588	0.0903	-0.0750	0.0603	-0.0559	0.0600
γ_{35}	0.1658	0.0965	0.1497	0.0946	0.1631	0.0743	0.1661	0.0750
γ_{36}	-0.0965	0.0432	-0.0935	0.0428	-0.0961	0.0421	-0.0863	0.0421

Table A.5.2.2 Estimates of Linear Dynamic Model

No Restrictions						Symmetry Restrictions					
	Estimate	Standard Errors		Estimate	Standard Errors		Estimate	Standard Errors		Estimate	Standard Errors
β_L	0.1510	0.1473	g_{12}	0.0785	0.0414	β_L	-0.0417	0.0927	g_{12}	0.0757	0.0408
β_{LL}	0.0113	0.0379	g_{13}	0.0122	0.0272	β_{LL}	-0.0120	0.0281	g_{13}	-0.0004	0.0267
β_{LD}	-0.0159	0.0196	g_{14}	-0.0155	0.0808	β_{LD}	-0.0009	0.0125	g_{14}	0.0107	0.0819
β_{LC}	0.2455	0.1356	g_{15}	0.0140	0.1618	β_{LC}	0.0221	0.0246	g_{15}	-0.1894	0.1057
β_{LK}	-0.3359	0.2156	g_{16}	0.0222	0.0721	β_{LK}	1.0000	0.0573	g_{16}	0.0969	0.0583
β_{LQ}	0.1253	0.0744	g_{22}	-0.0360	0.0295	β_{LQ}	0.0259	0.0443	g_{22}	-0.0380	0.0284
β_{LT}	0.0111	0.0055	g_{23}	0.0141	0.0194	β_{LT}	0.0029	0.0025	g_{23}	0.0091	0.0187
β_D	-0.0909	0.1049	g_{24}	0.0342	0.0575	β_D	-0.1652	0.0640	g_{24}	0.0449	0.0568
β_{DL}	0.0050	0.0270	g_{25}	0.0243	0.1152	β_{DL}	-0.0009	0.0125	g_{25}	-0.0500	0.0714
β_{DD}	-0.1678	0.0139	g_{26}	-0.0327	0.0513	β_{DD}	0.0035	0.0097	g_{26}	-0.0042	0.0404
β_{DC}	0.0858	0.0965	g_{32}	-0.0078	0.0324	β_{DC}	-0.0002	0.0128	g_{32}	-0.0078	0.0317
β_{DK}	-0.1646	0.1534	g_{33}	-0.0095	0.0213	β_{DK}	-1.0000	0.0357	g_{33}	-0.0036	0.0210
β_{DQ}	0.0885	0.0530	g_{34}	-0.0551	0.0633	β_{DQ}	0.0505	0.0307	g_{34}	-0.0672	0.0630
β_{DT}	0.0085	0.0039	g_{35}	0.1487	0.1266	β_{DT}	0.0052	0.0015	g_{35}	0.2547	0.1072
β_C	0.1623	0.1153	g_{36}	0.0080	0.0565	β_C	0.2574	0.0990	g_{36}	-0.0294	0.0516
β_{CL}	0.0062	0.0297	f_{11}	0.4921	0.2368	β_{CL}	0.0221	0.0246	f_{11}	0.8082	0.1409
β_{CD}	0.0083	0.0153	f_{13}	-0.2539	0.2295	β_{CD}	-0.0002	0.0128	f_{13}	-0.1277	0.2137
β_{CC}	-0.0315	0.1062	f_{13}	0.1865	0.2443	β_{CC}	0.0791	0.0811	f_{13}	0.4099	0.2118
β_{CK}	0.0226	0.1687	f_{21}	-0.0012	0.1685	β_{CK}	0.0000	0.1280	f_{21}	0.1204	0.0979
β_{CQ}	-0.1041	0.0583	f_{23}	0.4385	0.1633	β_{CQ}	-0.0546	0.0493	f_{23}	0.4918	0.1489
β_{CT}	-0.0044	0.0043	f_{23}	0.3466	0.1739	β_{CT}	-0.0004	0.0035	f_{23}	0.4344	0.1460
β_K	0.7776	n.a.	f_{31}	0.0822	0.1853	β_K	0.9495	n.a.	f_{31}	-0.0741	0.1572
β_{KL}	-0.0225	n.a.	f_{33}	0.0692	0.1796	β_{KL}	-0.0093	n.a.	f_{33}	0.0137	0.1724
β_{KD}	0.1754	n.a.	f_{33}	0.2689	0.1912	β_{KD}	-0.0025	n.a.	f_{33}	0.1612	0.1798
β_{KC}	-0.2999	n.a.				β_{KC}	-0.1011	n.a.			
β_{KK}	0.4778	n.a.				β_{KK}	0.0000	n.a.			
β_{KQ}	-0.1097	n.a.				β_{KQ}	-0.0217	n.a.			
β_{KT}	-0.0152	n.a.				β_{KT}	-0.0076	n.a.			

Note: The linear dynamic model refers to the linear model transformed from the original flexible model. Standard Errors are in parentheses. "n. a." refers to the value is not available.

Table A.5.2.2 (cont'd)

Homotheticity Restriciton						Symmetry & Homotheticity Restrictions					
	Estimate	Standard Errors		Estimate	Standard Errors		Estimate	Standard Errors		Estimate	Standard Errors
β_{L}	0.0257	0.1064	g_{12}	0.0759	0.0410	β_{L}	-0.0453	0.0890	g_{12}	0.0760	0.0394
β_{LL}	-0.0102	0.0334	g_{13}	0.0069	0.0267	β_{LL}	-0.0045	0.0262	g_{13}	-0.0038	0.0251
β_{LD}	-0.0074	0.0182	g_{14}	-0.0095	0.0801	β_{LD}	0.0004	0.0113	g_{14}	0.0243	0.0766
β_{LC}	0.0957	0.0609	g_{15}	-0.1297	0.1120	β_{LC}	0.0225	0.0217	g_{15}	-0.1802	0.1010
β_{LK}	-0.1038	n.a.	g_{16}	0.0722	0.0594	β_{LK}	0.0269	n.a.	g_{16}	0.0968	0.0563
β_{LQ}	0.0625	0.0541	g_{22}	-0.0380	0.0292	β_{LQ}	0.0218	0.0420	g_{22}	-0.0452	0.0279
β_{LT}	0.0050	0.0023	g_{23}	0.0099	0.0190	β_{LT}	0.0036	0.0020	g_{23}	0.0154	0.0179
β_{D}	-0.1904	0.0756	g_{24}	0.0390	0.0569	β_{D}	-0.1564	0.0628	g_{24}	0.0276	0.0544
β_{DL}	-0.0121	0.0238	g_{25}	-0.0898	0.0796	β_{DL}	0.0004	0.0113	g_{25}	-0.0525	0.0703
β_{DD}	0.0051	0.0129	g_{26}	0.0070	0.0422	β_{DD}	-0.0042	0.0086	g_{26}	-0.0050	0.0400
β_{DC}	-0.0332	0.0433	g_{32}	-0.0077	0.0320	β_{DC}	-0.0022	0.0114	g_{32}	-0.0159	0.0313
β_{DK}	0.2307	n.a.	g_{33}	-0.0092	0.0208	β_{DK}	0.1624	n.a.	g_{33}	-0.0038	0.0206
β_{DQ}	0.0386	0.0385	g_{34}	-0.0555	0.0624	β_{DQ}	0.0596	0.0296	g_{34}	-0.0654	0.0619
β_{DT}	0.0036	0.0016	g_{35}	0.1571	0.0873	β_{DT}	0.0036	0.0012	g_{35}	0.1954	0.0826
β_{C}	0.1697	0.0829	g_{36}	0.0050	0.0462	β_{C}	0.2021	0.0790	g_{36}	-0.0065	0.0457
β_{CL}	0.0074	0.0261	f_{11}	0.6920	0.1720	β_{CL}	0.0225	0.0217	f_{11}	0.8203	0.1336
β_{CD}	0.0078	0.0142	f_{13}	-0.1258	0.2034	β_{CD}	-0.0022	0.0114	f_{13}	-0.1754	0.1852
β_{CC}	-0.0226	0.0475	f_{13}	0.3365	0.2106	β_{CC}	0.0060	0.0395	f_{13}	0.4093	0.2048
β_{CK}	-0.1624	n.a.	f_{21}	0.1576	0.1222	β_{CK}	-0.2284	n.a.	f_{21}	0.0927	0.0944
β_{CQ}	-0.1004	0.0422	f_{23}	0.5403	0.1445	β_{CQ}	-0.0802	0.0390	f_{23}	0.6036	0.1285
β_{CT}	-0.0040	0.0018	f_{23}	0.4657	0.1496	β_{CT}	-0.0041	0.0017	f_{23}	0.4419	0.1446
β_{K}	0.9950	n.a.	f_{31}	0.0704	0.1340	β_{K}	0.9997	n.a.	f_{31}	0.0079	0.1248
β_{KL}	0.0149	n.a.	f_{33}	0.0617	0.1584	β_{KL}	-0.0184	n.a.	f_{33}	0.1301	0.1496
β_{KD}	-0.0055	n.a.	f_{33}	0.2600	0.1641	β_{KD}	0.0060	n.a.	f_{33}	0.2397	0.1645
β_{KC}	-0.0399	n.a.				β_{KC}	-0.0264	n.a.			
β_{KK}	0.0355	n.a.				β_{KK}	0.0391	n.a.			
β_{KQ}	-0.0008	n.a.				β_{KQ}	-0.0013	n.a.			
β_{KT}	-0.0046	n.a.				β_{KT}	-0.0030	n.a.			

Note: The linear dynamic model refers to the linear model transformed from the original flexible model. Standard Errors are in parentheses. "n. a." refers to the value is not available.

Table A.5.2.3 Estimates of Static Translog Models with Cost Equation

	No Restriction		Symmetry Restrictions		Symmetry & Homotheticity Restrictions	
	Estimate	Standard Errors	Estimate	Standard Errors	Estimate	Standard Errors
α_0	0.0496	0.0779	0.1702	0.1039	-0.0107	0.0966
β_L	0.4278	0.0100	0.4360	0.0185	0.4477	0.0195
β_{LL}	0.0442	0.0273	0.0766	0.0270	0.0859	0.0260
β_{LD}	-0.0319	0.0142	0.0048	0.0103	0.0111	0.0108
β_{LC}	0.3609	0.0370	-0.0215	0.0209	-0.0172	0.0194
β_{LK}	-0.5204	0.0636	-0.1644	0.0608	-0.0797	n.a.
β_{LQ}	0.1441	0.0430	-0.2017	0.0608	-0.2176	0.0634
β_{LT}	0.0128	0.0018	0.0019	0.0027	-0.0037	0.0018
β_D	0.0130	0.0072	0.0196	0.0097	0.0261	0.0097
β_{DL}	-0.0286	0.0199	0.0048	0.0103	0.0111	0.0108
β_{DD}	0.0214	0.0102	0.0416	0.0085	-0.0002	0.0127
β_{DC}	0.1139	0.0266	-0.0454	0.0241	-0.0108	0.0093
β_{DK}	-0.2196	0.0460	-0.1112	0.0437	0.0000	n.a.
β_{DQ}	0.0286	0.0309	-0.1266	0.0363	-0.0688	0.0330
β_{DT}	0.0118	0.0013	0.0067	0.0015	0.0034	0.0010
β_C	0.2670	0.0076	0.2675	0.0090	0.2671	0.0082
β_{CL}	-0.0301	0.0224	-0.0215	0.0209	-0.0172	0.0194
β_{CD}	0.0076	0.0110	-0.0454	0.0241	-0.0108	0.0093
β_{CC}	-0.0192	0.0283	0.1028	0.0266	0.0547	0.0264
β_{CK}	0.0527	0.0504	-0.0527	0.0488	-0.0267	n.a.
β_{CQ}	-0.1103	0.0323	-0.0103	0.0342	-0.0332	0.0338
β_{CT}	-0.0032	0.0014	-0.0003	0.0016	-0.0013	0.0012
β_K	1.0091	1.1844	1.1939	1.1224	0.2591	n.a.
β_{KL}	0.0578	0.4328	-0.1644	0.0608	-0.2246	n.a.
β_{KD}	0.0344	0.2692	-0.1112	0.0437	-0.0332	n.a.
β_{KC}	-4.0369	0.6195	-0.0527	0.0488	-0.0013	n.a.
β_{KK}	12.9787	2.8350	11.0782	2.6518	0.2591	n.a.
β_{KQ}	-2.7992	1.7132	-1.3232	1.5937	-0.2246	n.a.
β_{KT}	-0.4345	0.1248	-0.4602	0.1217	-0.0332	n.a.
β_Q	0.4964	0.4524	1.7407	0.4759	1.8725	0.4571
β_T	-0.0303	0.0585	-0.0897	0.0559	-0.0057	0.0138
β_{TQ}	3.9295	1.9852	3.8906	1.8758	2.2887	1.8512
β_{QQ}	0.0134	0.0059	0.0194	0.0056	-0.0013	0.0006
β_{TT}	0.0605	0.0866	0.0676	0.0815	-0.0282	0.0244

Note: "n. a." refers to the value is not available.

Table A.5.2.4 Estimates of Static Translog Models with Cost Equation with "ln *t*" for a time variable

	No Restriction		Symmetry Restrictions		Symmetry & Homotheticity Restrictions	
	Estimate	Standard Errors	Estimate	Standard Errors	Estimate	Standard Errors
α_0	0.1052	0.1605	-0.1621	0.2027	-0.2593	0.1940
β_L	0.4526	0.0281	0.4998	0.0305	0.5079	0.0263
β_{LL}	0.1446	0.0288	0.0727	0.0190	0.0514	0.0158
β_{LD}	-0.0177	0.0190	0.0273	0.8368	0.0271	0.8646
β_{LC}	0.2237	0.0582	-0.0218	0.0168	-0.0323	0.0120
β_{LK}	-0.4043	0.0815	-0.1080	0.0424	-0.0462	n.a.
β_{LQ}	0.0127	0.0706	-0.0580	0.0842	-0.0470	0.0760
β_{LT}	0.0012	0.0269	-0.0639	0.0262	-0.0725	0.0198
β_D	0.0341	0.0232	0.0604	0.0241	0.0381	0.0179
β_{DL}	0.0664	0.0267	0.0273	0.8368	0.0271	0.8646
β_{DD}	0.0266	0.0166	0.0617	0.0104	0.0217	0.0132
β_{DC}	-0.0133	0.0492	-0.1495	0.0324	-0.0258	0.8935
β_{DK}	-0.1012	0.0768	0.0387	0.0456	-0.0231	n.a.
β_{DQ}	-0.0888	0.0584	-0.1425	0.0647	-0.1050	0.0512
β_{DT}	0.0029	0.0223	-0.0327	0.0217	-0.0030	0.0138
β_C	0.2531	0.0148	0.2375	0.0154	0.2491	0.0151
β_{CL}	-0.0561	0.0192	-0.0218	0.0168	-0.0323	0.0120
β_{CD}	0.0045	0.0113	-0.1495	0.0324	-0.0258	0.8935
β_{CC}	0.0287	0.0325	0.1183	0.0267	0.0700	0.0248
β_{CK}	0.0065	0.0565	0.0050	0.0573	-0.0119	n.a.
β_{CQ}	-0.0885	0.0372	-0.0799	0.0379	-0.0405	0.0369
β_{CT}	0.0084	0.0144	0.0319	0.0143	0.0145	0.0133
β_K	4.4604	0.8987	2.2319	0.5686	0.9559	n.a.
β_{KL}	-1.3905	0.5046	-0.1080	0.0424	-0.9300	n.a.
β_{KD}	0.9041	0.3766	0.0387	0.0456	-0.0405	n.a.
β_{KC}	-2.2788	0.8913	0.0050	0.0573	0.0145	n.a.
β_{KK}	6.2239	2.0293	2.1964	0.9176	0.9559	n.a.
β_{KQ}	-2.0048	1.3022	-0.8607	1.2037	-0.9300	n.a.
β_{KT}	-2.4609	0.7906	-1.0542	0.4773	-0.0405	n.a.
β_Q	0.7611	1.2465	2.2287	1.2484	4.3361	0.7309
β_T	-0.6758	0.3160	-0.0022	0.2845	0.2507	0.1717
β_{TQ}	1.6277	4.1669	3.8251	3.7959	8.1341	2.8545
β_{QQ}	0.5481	0.4245	0.0153	0.3548	-0.1237	0.1074
β_{TT}	0.6667	1.3164	-0.0612	1.2224	-1.7159	0.5598

Note: "n. a." refers to the value is not available.

Table A.5.2.5 Parameter Estimates of Static Translog Model

	Unrestricted		Symmetry		Homothetic		Symmetry & Homothetic	
	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error
β_L	0.4266	0.0101	0.4219	0.0175	0.4285	0.0123	0.4252	0.0178
β_{LL}	0.0402	0.0298	0.0056	0.0413	0.0229	0.0343	0.0202	0.0373
β_{LD}	-0.0400	0.0146	0.0168	0.0243	-0.0669	0.0165	-0.0527	0.0153
β_{LC}	0.3631	0.0376	-0.0409	0.0135	0.2675	0.0360	0.0077	0.0207
β_{LK}	-0.5008	0.0671	-0.0120	0.0735	-0.2236	n.a.	0.0248	n.a.
β_{LQ}	0.1568	0.0430	-0.0971	0.0611	0.1195	0.0491	-0.0939	0.0595
β_{LT}	0.0130	0.0018	0.0053	0.0028	0.0078	0.0018	0.0037	0.0025
β_D	0.0123	0.0072	0.0110	0.0080	0.0141	0.0093	0.0122	0.0092
β_{DL}	-0.0312	0.0214	0.0168	0.0243	-0.0408	0.0255	-0.0527	0.0153
β_{DD}	0.0160	0.0105	0.0149	0.0255	-0.0035	0.0126	0.0016	0.0095
β_{DC}	0.1147	0.0270	0.0161	0.0093	0.0163	0.0099	-0.0039	0.0096
β_{DK}	-0.2053	0.0482	-0.0657	0.0463	0.0281	n.a.	0.0549	n.a.
β_{DQ}	0.0353	0.0309	-0.0384	0.0331	-0.0147	0.0312	-0.0331	0.0315
β_{DT}	0.0119	0.0013	0.0097	0.0013	0.0073	0.0012	0.0074	0.0012
β_C	0.2670	0.0076	0.2733	0.0097	0.2663	0.0077	0.2731	0.0085
β_{CL}	-0.0310	0.0224	-0.0409	0.0135	-0.0380	0.0214	0.0077	0.0207
β_{CD}	0.0083	0.0110	0.0161	0.0093	-0.0039	0.0096	-0.0039	0.0096
β_{CC}	-0.0188	0.0283	0.1129	0.0280	0.0012	0.0262	0.0578	0.0270
β_{CK}	0.0519	0.0505	-0.1831	0.0524	0.0407	n.a.	-0.0617	n.a.
β_{CQ}	-0.1101	0.0323	-0.0121	0.0369	-0.1031	0.0325	-0.0475	0.0350
β_{CT}	-0.0031	0.0014	-0.0012	0.0017	-0.0025	0.0012	-0.0030	0.0013
β_K	0.2941	n.a.	0.2937	n.a.	0.2911	n.a.	0.2895	n.a.
β_{KL}	0.0220	n.a.	0.0185	n.a.	0.0559	n.a.	0.0248	n.a.
β_{KD}	0.0158	n.a.	-0.0477	n.a.	0.0743	n.a.	0.0549	n.a.
β_{KC}	-0.4589	n.a.	-0.0881	n.a.	-0.2850	n.a.	-0.0617	n.a.
β_{KK}	0.6542	n.a.	0.2607	n.a.	0.1548	n.a.	-0.0181	n.a.
β_{KQ}	-0.0820	n.a.	0.1476	n.a.	-0.0018	n.a.	0.1745	n.a.
β_{KT}	-0.0218	n.a.	-0.0139	n.a.	-0.0126	n.a.	-0.0081	n.a.

Note: "n. a." refers to the value is not available.

Table A.5.2.6 Estimates of Cobb -Douglas Models

	No Restrictions		Symmetric Restrictions	
	Estimate	Standar Error	Estimates	Standar Error
β_o	0.0827	0.0744	0.1777	0.0894
β_L	0.4040	0.0070	0.4040	0.0071
β_D	0.1107	0.0088	0.1104	0.0089
β_C	0.1557	0.0085	0.1560	0.0086
β_K	0.4607	0.1439	0.3296	n.a.
β_Q	1.1043	0.1538	0.8571	0.2207
β_T	-0.0623	0.0069	-0.0001	0.0028

Note: "n. a." refers to the value is not available.

Table A.5.2.7 Allen's Partial Elasticities of Substitution Estimated by the Flexible Model

	Unrestricted				Symmetry				Symmetry & Homothetic			
	L	D	C	K	L	D	C	K	L	D	C	K
L	-1.451 (0.409)	0.433 (0.688)	6.781 (1.663)	-2.324 (1.543)	-1.613 (0.709)	1.235 (1.035)	1.184 (0.584)	2.260 (2.007)	-1.245 (0.705)	1.563 (1.077)	1.450 (0.601)	0.311
D	1.509 (0.979)	-8.346 (1.651)	11.730 (3.981)	-9.165 (3.696)	1.235 (1.035)	-6.774 (2.000)	1.668 (1.201)	-1.010 (3.358)	1.563 (1.077)	-7.530 (2.559)	1.006 (1.140)	0.053
C	1.195 (0.578)	1.479 (0.970)	-4.548 (2.347)	-0.153 (2.181)	1.184 (0.584)	1.668 (1.201)	-5.297 (4.671)	0.405 (4.022)	1.450 (0.601)	1.006 (1.140)	-4.728 (2.173)	0.167
K	0.699	1.459	-9.830	5.837	2.260	-1.010	0.405	-2.606	0.311	0.053	0.167	-0.476

Note: Standard Errors are in parentheses.

Table A.5.2.8 Allen's Partial Elasticities of Substitution Estimated by the Static Model

	Unrestricted				Symmetry				Symmetry & Homothetic			
	L	D	C	K	L	D	C	K	L	D	C	K
L	-1.328 0.167	0.253 0.291	6.272 0.557	-2.440 0.454	-1.059 0.198	0.703 0.507	0.907 0.188	2.061 0.468	-0.937 0.156	1.308 0.245	0.575 0.301	0.436 (n.a.)
D	-0.052 0.405	-6.414 0.792	6.912 1.450	-4.015 1.235	0.703 0.507	-4.320 2.142	2.829 0.523	-1.481 1.073	1.308 0.245	-7.842 1.103	0.811 0.544	0.555 (n.a.)
C	0.367 0.512	1.358 0.938	-5.863 1.646	1.829 1.401	0.907 0.188	2.829 0.523	-2.015 1.070	-1.520 0.939	0.373 0.445	0.811 0.804	-3.275 1.533	0.598 (n.a.)
K	1.350 (n.a.)	1.112 (n.a.)	-7.035 (n.a.)	3.375 (n.a.)	2.061 (n.a.)	-1.481 (n.a.)	-1.520 (n.a.)	-1.299 (n.a.)	0.436 (n.a.)	0.555 (n.a.)	0.598 (n.a.)	-0.995 (n.a.)

Note: Standard Errors are in parentheses.

Table A.5.2.9 Price Elasticities of Factor Demand Estimated by the Flexible Model

	Unrestricted				Symmetry				Symmetry & Homothetic			
	L	D	C	K	L	D	C	K	L	D	C	K
L	-0.583 (0.164)	0.174 (0.277)	2.726 (0.668)	-0.934 (0.620)	-0.648 (0.285)	0.496 (0.416)	0.476 (0.235)	0.908 (0.807)	-0.500 (0.283)	0.628 (0.433)	0.583 (0.242)	0.125
D	0.161 (0.105)	-0.893 (0.177)	1.255 (0.426)	-0.981 (0.395)	0.132 (0.111)	-0.725 (0.214)	0.179 (0.128)	-0.108 (0.359)	0.167 (0.115)	-0.806 (0.274)	0.108 (0.122)	0.006
C	0.189 (0.091)	0.234 (0.153)	-0.719 (0.371)	-0.024 (0.345)	0.187 (0.092)	0.264 (0.190)	-0.837 (0.738)	0.064 (0.636)	0.229 (0.095)	0.159 (0.180)	-0.747 (0.343)	0.026
K	0.232	0.484	-3.264	1.938	0.750	-0.335	0.135	-0.865	0.103	0.018	0.056	-0.158

Note: Standard Errors are in parentheses.

Table A.5.2.10 Price Elasticities of Factor Demand Estimated by the Static Model

	Unrestricted				Symmetry				Symmetry & Homothetic			
	L	D	C	K	L	D	C	K	L	D	C	K
L	-0.534 (0.067)	0.102 (0.117)	2.521 (0.224)	-0.981 (0.182)	-0.426 (0.080)	0.282 (0.204)	0.365 (0.076)	0.829 (0.188)	-0.377 (0.063)	0.526 (0.099)	0.231 (0.121)	0.175
D	-0.006 (0.043)	-0.686 (0.085)	0.740 (0.155)	-0.430 (0.132)	0.075 (0.054)	-0.462 (0.229)	0.303 (0.056)	-0.158 (0.115)	0.140 (0.026)	-0.839 (0.118)	0.087 (0.058)	0.059
C	0.058 (0.081)	0.215 (0.148)	-0.926 (0.260)	0.289 (0.221)	0.143 (0.030)	0.447 (0.083)	-0.318 (0.169)	-0.240 (0.148)	0.059 (0.070)	0.128 (0.127)	-0.518 (0.242)	0.094
K	0.448	0.369	-2.336	1.121	0.684	-0.492	-0.505	-0.431	0.145	0.184	0.199	-0.330

Note: Standard Errors are in parentheses.

Table A.5.2.11 Output Elasticities of Factor Demand Estimated by the Flexible Model

	Unrestricted				Symmetry				Symmetry & Homothetic			
	L	D	C	K	L	D	C	K	L	D	C	K
Estimate	1.360 (0.265)	1.868 (0.636)	0.268 (0.375)	0.633	0.508 (0.403)	0.314 (0.699)	0.141 (0.752)	2.226	0.481 (0.383)	0.265 (0.822)	0.263 (0.445)	2.216

Note: Standard Errors are in parentheses.

Table A.5.2.12 Output Elasticities of Factor Demand Estimated by the Linear Dynamic Model

	Unrestricted				Symmetry				Symmetry & Homothetic			
	L	D	C	K	L	D	C	K	L	D	C	K
Estimate	1.312 (0.185)	1.827 (0.495)	0.341 (0.369)	0.670	1.064 (0.110)	1.472 (0.287)	0.654 (0.312)	0.935	1.054 (0.104)	1.557 (0.277)	0.493 (0.247)	0.996

Note: The linear dynamic model refers to the linear model transformed from the original flexible model.
Standard Errors are in parentheses.

Table A.5.2.13 Output Elasticities of Factor Demand Estimated by Static Model

	Unrestricted				Symmetry				Symmetry & Homothetic			
	L	D	C	K	L	D	C	K	L	D	C	K
Estimate	1.318 (0.107)	1.192 (0.287)	0.347 (0.204)	0.864	1.457 (0.150)	0.610 (0.300)	0.833 (0.212)	0.652	0.420 (0.160)	0.412 (0.308)	0.746 (0.210)	2.013

Note: Standard Errors are in parentheses.

Table A.5.2.14 Elasticities of Scale with respect to Output in Static Models

	No Restrictions	Symmetry Restricitons	Symmetry & Homotheticity Restrictions
Estimates	0.168 (0.506)	1.366 (0.474)	2.476 (0.480)

Note: Standard errors are in parantheses.

Table A.5.2.15 Elasticities of Technological Changes Estimated the Flexible Dynamic Model

	No Restrictions	Symmetry Restricitons	Symmetry & Homotheticity Restrictions
Labor	0.028 (0.014)	0.007 (0.006)	0.003 (0.016)
Land	-0.079 (0.036)	-0.049 (0.014)	0.043 (0.029)
Chemical	-0.028 (0.027)	-0.003 (0.022)	-0.027 (0.014)
Capital	-0.046	-0.023	-0.004

Note: Standard errors are in parentheses.
An ordinary Time Trend Variable (T) are used.

Table A.5.2.16 Elasticities of Technological Changes Estimated in the Static Model

	No Restrictions	Symmetry Restricitons	Symmetry & Homotheticity Restrictions
Labor	0.031 (0.004)	0.006 (0.007)	-0.010 (0.004)
Land	0.111 (0.012)	0.088 (0.012)	0.033 (0.009)
Chemical	-0.001 (0.009)	-0.006 (0.009)	-0.008 (0.008)
Capital	-1.671 (0.458)	-1.510 (0.389)	5.693

Note: Standard errors are in parentheses.
An ordinary Time Trend Variable (T) are used.

Table A.5.2.17 Elasticities of Technological Changes Estimated in the Flexible Dynamic model with Linear Time Trend Variables

	No Restrictions	Symmetry Restricitons	Symmetry & Homotheticity Restrictions
Labor	0.003 (0.067)	-0.159 (0.065)	-0.180 (0.049)
Land	0.027 (0.208)	-0.305 (0.203)	-0.028 (0.129)
Chemical	0.053 (0.091)	0.202 (0.090)	0.092 (0.084)
Capital	-6.039	-2.593	-2.801

Note: Standard errors are in parentheses.
The time trend variable in translog equation is ln t, where t=1,2, ...,T.

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