Modelling Grain Production in China with Supply Response and Self-Sufficiency Analysis

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Dedicated to my parents with love.

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CHAPTER 1

INTRODUCTION

China is one of both the largest grain producers and consumers in the world. However, with its fast-paced industrialization, more and more researchers have started to look seriously into the potential of self-sufficiency for China in the near future.

Brown (1995), president of the WorldWatch Institute, has recently predicted that with its rapid economic growth, the loss of cropland in China will quickly exceed the rise in land productivity, leading to a substantial decline in grain production over the coming decades, causing a reduction in grain production of one-fifth between 1990 and 2030. Meanwhile, the climbing income per capita will raise the consumption of livestock products and the demand for grain. As a result, China will face the feeding issue of a gap between supply and demand of 378 million tonnes of grain per year by 2030.

However, adopting different approaches from that used by Brown (1995) and emphasizing the prediction of grain production, Chinese researchers arrived at opposite results. According to Julian Simon, economist of the University of Maryland and Dennis Avery of the Hudson Institute, as long as China keeps growing in GDP steadily, it is economically feasible to import grain to cover the gap between grain production and consumption.[1] A more realistic scenario may be that China will become an increasingly active trader in the world agricultural

[1]Holloway (1995). "No Pain, No Grain", *Far Eastern Economic Review*, November 16.

markets, producing some agricultural products for export and importing others.[2]

In this paper, projections will be made on the Chinese grain production for the next three decades based on the empirical results obtained from proposed Cobb-Douglas production functions and supply response functions. Depending on the approaches adopted, predictions of the gap between grain consumption and production can vary dramatically. Since quantitative research in Chinese grain economy was very limited and insufficient, the modelling of the grain production in China is extremely challenging and interesting.

The main purpose of this paper is to examine China's grain production and analyze the potential for self-sufficiency. The emphasis is on obtaining more reliable predictions based on empirical results and a set of assumptions and possible scenarios for policymakers, rather than on getting the precise numbers. Of course, uncertainties associated with technological improvement, government polices and other factors remain. Even if the prediction of the grain deficit or surplus for the next three decades may not be the actual outcome, it is hoped that the paper will be constructive for future studies regarding the causes of changes in grain production and consumption, as well as policy implications and suggestions regarding grain production and consumption in China. These are precisely the objectives of this study.

The empirical work described here covers the period 1952 to the early 1990s. The historical development of Chinese grain economy is highly influenced by the government policies and political environment. Since the founding of the People's Republic China in 1949, the government has tightly controlled and influenced all aspects of the agriculture sector. As for

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[2] The State of Food and Agriculture 1995, FAO, 236-239.

grain production, in addition to other major factors, such as the total amount of land allocated for grain production, capital inputs, and natural conditions, government policy directly affected basic production decisions of farmers, especially through the pricing systems. The main tenet of the empirical results in this study is that erratic changes in policies help explain the zigzag trends of Chinese grain production and have a direct impact on future production. It is believed[3] that the choice of government policy will not only be an essential determinant of grain supply and demand in China, but also affect the rest of the world.

The paper is organized as follows. In Chapter 2, the fundamental elements of grain production and consumption based on the relevant economic literature are briefly analyzed. In Chapter 3, several models are proposed with an emphasis on aggregate production function and supply response analysis; then projections are made for the grain production in year 2000 and 2030. Concluding remarks are given in Chapter 4, followed by statistical tables and simulations in Appendix A and Time-series analysis in Appendix B.

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[3]OECD (1995).

CHAPTER 2

A GENERAL ANALYSIS OF GRAIN PRODUCTION AND CONSUMPTION IN CHINA

In this chapter, general features of the agriculture sector of China will be introduced first. Next, the trends of grain consumption and the widely accepted projections of grain consumption of China that will be used in Section 3.5 are discussed. The last section of this chapter will focus on analyzing the key factors of grain production of China.

2.1 General features of the natural resource endowment/agriculture in China

Although China is now considered one of the most promising emerging markets in the world for most industries, it is still heavily based on agriculture. Approximately 71.86 % of the Chinese population still lives in the countryside; 56.4% of the total labor force is involved in the agricultural sector; and 21.20 % of GNP is accounted for by the agriculture sector (Statistical Yearbook of China, 1994).

The total territory of China is 9.6 million km^2. It ranks third in size in the world and the geographic and climatic richness is unequalled by any other country. Of the total land area, mountains account for 33%, plateaux for 26%, basins for 19%, plains for 12% and hilly lands for 10%. However, the total arable land in China is extremely limited. It could be considered as a miracle that China has fed 22% of the world's population with only 7% arable land of the world over the past four decades.

There are five general characteristics of China's agriculture. First, the huge population in relation to the limited base of arable land poses an unparalleled challenge for China to maintain self-sufficiency. Second, substantial efforts have been made to improve agricultural production conditions, especially the use of chemical fertilizers, irrigation and farm machinery since 1949. Third, the diversity of China's natural endowments leads to a highly diversified agricultural sector. Thus, it is a challenge for any researcher to carry out empirical studies on the agriculture sector in China at the aggregate level. Fourth, as for grain production, it is noted that grain production has always been the biggest item of China's agriculture since 1952. Detailed analysis of the trends and features of grain production will be presented in Section 2.3. Finally, as in other countries, food and grain consumption in China is basically determined by population growth and the increase in per capita disposable income.

2.2 Grain consumption in China

Demographic situation

China's population growth rate, with the exception of the late 1980s, has continued to decrease. China is now in the latter stage of Phase II in the context of demographic transition[4], which features with both a decreasing crude birth rate and a decreasing death rate. The birth rate declined from 3.7% in 1952 to 1.809% in 1993 and population growth has begun to stabilize. The decline in fertility is driven largely by China's socioeconomic factors, such as rising real income per capita, improved living standards and education, as well as the increasing participation of women in the labor force. The latest available data show the total population at

[4] "Does sustainability require growth", by Richard Baldwin (1992), from *The Economics of Sustainable Development*, Chapter 3.

1.20778 billion on October 1, 1995, up 6.54% from 1990. Moreover, compared with the period of 1986-90, the annual growth rate has slowed by 0.34 percentage points over the past five years. In 1995, the population growth rate was 10.55 per thousand, whereas it was 14.39 in 1990 and 11.45 per thousand in 1993.[5]

It is widely accepted that China's population will grow annually at a rate of less than 1% and increase by more than 10 million people a year. China is expected to add about 400 million people between 1995 and 2030, with a population of 1.6 billion at the end of this period. The estimate for the year 2000 under this growth rate is 1.27 billion. These figures will be one base of the scenario analysis in Section 3.5. However, these estimates are quite optimistic. Indeed, to keep China's population no higher than 1.6 billion by 2030 requires an annual growth rate of 0.82% while the lowest rate up to now is 1.025% in 1995. In addition, there is another concern that the reported statistics underestimate the true population size because many families, especially those in rural areas, do not report their second child in order to avoid the penalty due to the breaking of family planning policy. Therefore, population levels of 1.77 billion in year 2030 and 1.29 billion in 2000 will be the other bases of the scenario analysis in Section 3.5, which assumes, in a conservative manner, that the annual growth rate will remain at 1.1% instead of 0.82% over the next 35 years.

Consumption per capita and economic growth

Analysts of the world food supply-demand balance have recognized that grain

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[5]The latest data cited are from China Daily, March 24, 1996, and the figure is based on the results of the 1995 nationwide one-percent population sample survey. That is, over 12 million people, from more than 40,000 urban neighbourhood committees and rural villages from 30 municipalities, provinces and autonomous regions were surveyed by the State Statistics Bureau.

consumption in China would climb dramatically as industrialization accelerated and incomes rose[6]. These researchers have also assumed that rapid growth in grain production in China would continue indefinitely.

With regards to the economic growth of China, the recorded real GDP growth is 13.6% in 1992, 13.4% in 1993, 11.8% in 1994, and another two-digit increase in 1995 that adds up to a phenomenal 50-per-cent expansion of the Chinese economy in just four years. Never before have incomes for so many people risen so quickly. This rapid economic expansion promises to push up demand for food at a record rate. As incomes rise, one of the first things low-income individuals will do is to diversify their diets, shifting from a monotonous fare in which a starchy staple, such as rice supplies 70 percent or more of the calories, to one that includes meat, milk, and eggs. As consumption of pork, beef, poultry, eggs, milk, and other livestock products increases along with income, grain requirements rise rapidly.

Therefore, accompanying the economic growth and increase of income in the next century, the level of grain consumption in China will further rise. A reliable estimate is that the per capita consumption of grain by the Chinese will most likely increase to 400 kg per year, approaching the early 1990s levels of Japan, a developed Asian country with a similar food consumption structure. Since grain consumption is exogenous to the econometric models this paper will introduce, any predictions regarding grain consumption are somewhat arbitrary. For simplicity, a widely-accepted 0.2% growth rate for grain consumption per capita, which is corresponding to the estimate of 380 kg per capita consumption in 2000 and 400 kg in 2030, will be chosen for forecasting purposes, and it will not be difficult to extend the scenario analysis by

[6] 'Who will feed China?', by Lester R. Brown, ECODECISION, Autumn 1995.

choosing more possible growth rates for grain consumption per capita.

In summary, based on the estimate of the annual per capita grain consumption growth rate of 0.2%, the total consumption for grain in China will be approximately 476 million tonnes per year with a population of 1.6 billion or 483 million tonnes with a population of 1.77 billion by the year 2000; the figures for year 2030 under both low and high assumptions will be 646 million and 712 million tonnes, respectively.

2.3 Major factors and inputs in grain production

Two main features of grain production have been observed. On the one hand, there was substantial growth in grain output between 1952 and 1993, which was mainly induced by the large injection of modern inputs and technological improvement in production. On the other hand, the production of grain followed an unsmooth path during this period. This development pattern can be attributed primarily to shifts in government policy, as well as other random shocks and variation of natural conditions. The following analysis will serve as the introduction for the econometric analysis in Chapter 3.

The shrinkage of cultivated acreage in total

The cultivated land as a whole shrank from 993.895 million in 1978 down to 951.014 million hectares at the end of 1993, with an average annual decreasing rate of 0.33%. The major reasons for the loss of cultivated land included capital construction by the state, village collective construction, and peasants' individual construction. Besides the listed causes, which only amount to less than half the land loss, illegal occupation of cropland and other unnecessary and avoidable uses crowd out substantial good land. Land plays an important role in estimating the grain production function in Section 3.3 and the supply response analysis in Section 3.4, where total sown area of grain will be chosen to represent the land inputs.

The total output of grain analysis

According to the analysis of Brown (1995), China today has many similarities with mid-20th century Japan, since both economies have been densely populated in agronomic terms. Harvested grain land per person in Japan in 1950 was 0.08 hectares, compared with 0.07 hectares in China today, and by the mid-20th century, Japan's industrialization was well underway.

Furthermore, there are several key reasons why China's grain deficit could grow even faster than that of Japan: one is the lack of a seafood option and the other is that Japan did not have to face the growing diversion of irrigation water to urban and industrial uses. Another contrast between the China of today and the Japan of forty yeas ago is the grain yield potential. The unrealized yield potential of each of the three major grains--rice, wheat, and corn in China today is likely to be much less that it was in Japan at a comparable stage of industrial development.

Meanwhile, between 1990 and 1994, China's grain-harvested area shrank by more than 1% a year with the grain yield per acre rising by less than 1% annually; thus, total grain output has been declining slightly. In the case of Japan, the decline in grain production started after 1960, with output falling by approximately 1% a year, for a total of 32% by the end of 1990. For China, the initial estimates put the 1995 grain harvest at 337 million tonnes, 1% below that of 1990. Using the Japanese model and looking ahead to 2030, an assumption would be that China's grain production would fall by at least one fifth to 272 million tonnes.

However, it is not reasonable to predict the future output based only on the short period between 1990 and 1994. It could be more reliable to study the trend from 1952, when the State Statistical Bureau of China was founded and started to collect and release statistics on the Chinese economy. The annual growth rate of grain production from 1952 to 1993 is approximately 0.507%, whereas the rate from 1978 to 1993 when China initiated the Economic Reform and Open Door Policy is 1.9%. Meanwhile, the annual rate of total sown land lost is 0.252% over the past forty-two years and 0.293% over the latest sixteen years. In fact, after the sharp decline of 2.5% during the period 1993-1994, the total grain output[7] of China jumped 3.5% in 1995, in the opposite direction predicted by Brown (1995). Although the data vary from source to source, it seems more reliable to estimate the trend according to the annual growth rate derived from the historical data instead of the numbers for certain years. According to this approach, the total grain output of China will increase to 882 million tonnes by 2030 based on the trend from 1978 to 1993.

Compared with the predicted decline by one-fifth over the coming 35 years, the annual growth rate of 1.9% during the period 1978-1993 might be too optimistic.

Labor Input

Another important explanatory variable in the proposed grain production functions, the labor force in agriculture, grew approximately 1.86% per year during 1952-1993. Note that it would be more appropriate to conduct an analysis based on the quantity of effective labor inputs rather than on the crude data on the labor force. However, such attempts are constrained by limited resources and techniques. Therefore, it is expected that the impact of labor input on grain production in China may not be correctly identified, and further discussion will be needed while

[7]Economic Forecast of 1996, China National Information Centre.

modelling the grain production functions and conducting supply response analysis.

Environmental constraints[8] and Irrigation

As the FAO reported in 1995, the Asian and Pacific countries must confront the related resource issues of land degradation and increasing water scarcity to sustain agricultural and food production growth. A significant proportion of Asia's land in crop production is fragile; this includes arid and rain-fed semiarid areas, areas with unreliable rainfall, and areas with steep slopes and/or poor soils. It is in these areas that environmental degradation and rural poverty tend to be most severe.

FAO estimates that the uncropped cultivable area in South Asia is 0.051 hectares per person; the figure for China is 0.07. The limited cultivable area for expansion and the continuing conversion of fertile agricultural land into non-agricultural uses mean that production increases have to come mainly from yield increases.

Yield increases, however, will be difficult to accomplish given the quickening pace of land degradation and water scarcity. The most damaging factors are soil erosion, nutrient mining, salinisation of soils, and loss and contamination of water. The extent and intensity of land degradation and water scarcity are difficult to measure; however, it is obvious that the drag on yield growth caused by unsustainable farming systems has become a serious problem in China, where the vicious circle of poverty and environmental degradation has been established in certain regions such as the Qinghai and the Gansu provinces.

Along with the continuing disappearance of farmland, China is also confronted with an extensive diversion of irrigation water to non-farm uses -an acute concern in a country where half

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[8] The State of Food and Agriculture 1995, FAO.

of the cropland is irrigated and nearly four-fifths of the grain harvest come from irrigated land. With large areas of north China now experiencing water deficits, existing demand is being met partly by depleting aquifers. Satisfying much of the growing urban and industrial demand for water in the arid northern half of the country will depend on diversions from irrigation.

Since 1950, China's water supply-demand balance has deteriorated as water use has increased sixfold. Causes for the increase have been population growth, irrigation expansion, rising affluence and industrialization. In an environment threatened by global warming, even a modest loss of rainfall or increase in evaporation could disrupt China's finely tuned, highly productive agriculture.

Mechanization, chemical fertilizer and the double effects of industrialization on grain production and consumption in China

The steady process of mechanization and the increasing use of chemical fertilizer have been the other two major contributors to the rise of grain output in China.

Although agricultural activities in China are traditionally highly labor intensive, a steady process of mechanization has been underway mainly in the form of increases in the supply of electricity and petroleum to grain production. By the end of 1993, the stock of mechanized farm power totalled 31.8 million kw, including 721,216 units of large and medium tractors and 9.65 million units of tractor-towing farm machinery. The machine-ploughed areas totalled 42 million hectares, amounting to over two-fifths of all farmland, and the machine-sown area accounted for more than one-tenth of the total.

Chemical fertilizer in China has had a significant impact on yields since the early 1950s. The chemical fertilizer industry was established in 1949 and has grown dramatically since then.

During the Fourth Five-Year Plan period (1971-75), 13 large scale chemical fertilizer plants were imported by the Chinese government. These major plants, in addition to more than 1,300 small nitrogenous fertilizer plants and approximately 50 medium-sized enterprises, form a network of chemical fertilizer production throughout the country. Chemical fertilizer consumption in 1952 amounted to only 78,000 tonnes, while 31.5 million tonnes were applied by 1993.

Because the improvement in the level of mechanization and the use of chemical fertilizer have been critical in the sustained increase in grain output, both factors will be quantified and integrated into the econometric models introduced in the next Section. However, due to the poor quality of the data regarding these two factors and the limits of modelling techniques, caution is required to relate the empirical results to the real effects of these inputs on grain production.

Although industrialization has enabled the improvement in both mechanization and chemical fertilizer inputs, it has also had negative effects on both grain production and consumption. Therefore, a brief analysis of the double effects of industrialization is now presented.

It is natural to compare the development of China with its eastern neighbours, Japan, South Korea and Taiwan, which, historically, were densely populated in agronomic terms before industrialization. The common experience of these three economies may give us a sense of what to expect as industrialization proceeds in China; for instance, the conversion of cropland to other uses in these areas over the last few decades has cost Japan 52 percent of its cropland; South Korea 46 percent; and Taiwan 42 percent. As cropland losses accelerated, they soon exceeded increases in land productivity, leading to steady declines in output. At the same time, while production was falling, rising affluence began to drive up the overall demand for grain. As a result, by 1994, Japan, South Korea and Taiwan were collectively importing 71 percent of their grain[9]. Although it might not be appropriate to declare that China will suffer the same rapid cropland losses as its neighbours, it should be noted that the similar forces are at work in China in her transformation from an agricultural to an industrial society at a breakneck pace. That is, increased per capita income raises food consumption while industrialization itself tends to crowd out cultivated land.

Pricing systems

Price is another factor related to grain production in China that has been important but hard to measure. When economic reform began in the late 1970s, the State bought a quota of grain from each farmer at an artificially low official price. Any surplus could be sold on the free market. In 1993, China gave farmers more encouragement by abolishing quotas and freeing up all prices. However, when grain prices in the cities doubled, government planners quickly reinstated price ceilings and quotas because of the fear of social instability caused by the high inflation rate.

With controls back in place, peasants get limited rewards for their hard work. The central government requisitions grain in each province -up to 40 percent of peasants' harvest -and purchases it at scarcely half the market price. In fact, state prices have not risen since 1994, despite a 24% general inflation in that year. With grain-purchase prices fixed at a rather low level, peasants respond with diversionary tactics, ranging from illegal resistance to leaving the farm for more lucrative work elsewhere. The same thing happened to cotton production in 1994 resulting in many defaults on garment orders and the shift of foreign buyers to other sources of supply.

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[9]Source: U.S. Department of Agriculture (1995).

In this study, the price factor is considered an important element related to government policy, that affects grain production supply in the short term. Further discussion will be followed in the same subsection on government policy analysis below and in Section 3.4.

Government Policy

As just discussed, unfavorable government policies lead to the short-sighted behavior of individual farmers and result in unsustainable grain production. Fortunately, according to the latest news from *China Daily* and *Beijing Review*, the central government of China pledged to give priority to the farming sector in terms of fund allocation, policies to encourage farming, and technology. According to the Great-Plan-for-the-Year-2000, the State hopes to register an annual grain output of some 490 million to 500 billion tonnes. The targets outlined in 1996 include accelerating construction of farmland irrigation systems and stabilizing cereal-growing acreage at 110 million hectares. Also, advanced practical agricultural techniques will be disseminated. Issues, such as low prices of agro-products, methods for supplying and marketing chemical fertilizers, and the heavy economic and tax burdens on farmers, are higher on the agricultural agenda of 1996 than those in the past for government attention. If appropriate policies are implemented, the increase in grain yield and total output could be promising.

It is generally agreed that the development of China's grain production was influenced by three major policy ingredients: (1) rural institutions and production organization; (2) the decision-making structure and production management system; and (3) the agricultural pricing and marketing system. Government policies during the last four decades can be categorized into two patterns summarized in Table 2.1.

Table 2.1 Two government policy patterns for grain production in China

	Policy Pattern A	Policy Pattern B
General strategy for the development of agriculture	Diversified development	Take grain as the link
Policy on rural institutions and production organization	Co-operatives	Collectives
Policy on decision-making and production management	Indirect control	Direct control
Policy on pricing and marketing system	Looser control and improved prices	Tight control and unfavorable farm prices
Relevant periods	1952-1957 1961-1965 1978-1984 1989-1993	1958-1960 1966-1977 1985-1988[10]

Although government policies changed over time and took different forms in different periods during 1952-1993, two basic policy patterns can be identified. The policies pursued during the periods 1952-1957, 1961-1965, 1978-1984 and 1989-1993, which are generally in favor of grain production, are classified as Policy Pattern A, and those for the periods 1958-1960, 1966-1977 and 1985-1988 as Policy Pattern B.Since more detailed investigations can be found in the studies of Johnson (1996, V.1), OECD (1995), Chen and Buckwell (1991) and Lardy (1983), only an outline of these two pattern government policies is presented as follows:

[10]The period 1984-88 is commonly agreed as the stage of marketization and stagnation of grain production, although differences from the rest of the eras in Policy Pattern B are apparent. The empirical results later show that the policy during 1984-88 is statistically in accordance with Policy Pattern A instead of B.

The common features for Police Pattern A during the periods of 1952-1957 (The First Five-Year Plan), 1961-1965, 1978-1984 (The Household Responsibility System) and 1989-1993 are: (1) the important role of the peasant households in the development of grain production and the adoption of responsibility system inside the basic production units; (2) the encouragement of household sidelines, free markets and private plots production; (3) the co-operative ownership and its responsibility for production management and decision-making was protected; (4) Pricing and marketing policies were used as the main policy instruments for inducing the development of agricultural production. As a result, certain bargaining power in procurement was placed in the farmers' hands, and government targets for grain procurement were designed with caution, whether consciously or involuntarily. This policy pattern is referred to as co-operatives and indirect control in Table 2.1.

In Policy Pattern A, the period cf household responsibility system reform (1978-1984) has proven to have been the most important single reform measure. It was initially introduced unofficially in China. From 1978, farmers in poor regions secretly experimented with household-based production responsibility systems. Good harvests by teams that adopted the experiment attracted other to the scheme in the next year. In 1979, only 1% of all production teams adopted this system. The system was finally recognized by the government at the beginning of the 1980s and the acceptance rate grew to 45% in 1981 and nearly 98% of production teams had adopted the household responsibility system by the end of 1983 (OECD, 1995). Under this system, land is contracted to households for 15 to 30 years. One of the most important advantages of the household responsibility system in comparison with the previous commune system is that farmers' economic returns are more closely and directly related to effort. Therefore, farmers have an incentive to adjust their behavior in response to changes in economic signals and other factors.

The basic features for Police Pattern B during the periods of 1958-1960 (Great Leap Forward), 1966-1977 (The Cultural Revolution) and 1985-1988 are: (1) the importance of agricultural production was not emphasized, the ownership and freedom of the basic production units were neglected; (2) constraints or prohibition on private plots, household sidelines and the free market; (3) the decision-making and production management systems were under great political pressure. The directives from the central government were executed mechanically or were further exaggerated by the local governments; (4) purchasing prices for grain and other agricultural products stagnated, and the price gap between agricultural and industrial goods widened. Political pressures were imposed on grain procurement, and a high proportion of the crop was officially purchased given the low level of per capita grain production. This pattern is referred to as collectives and direct control.

It will become apparent that the complexities of China's policies on agriculture can hardly be captured by relatively simple quantitative analysis, although they become quite significant when combined with price factors during each period.

In addition to the elements identified above, other important factors, such as technology improvement, natural conditions and farmers' education level, also exert significant impacts on grain production. The econometric modelling conducted in the next Chapter will be based on the qualitative analysis presented in this Section.

CHAPTER 3

MODELLING THE GRAIN PRODUCTION FUNCTION IN CHINA 1952-1993

3.1 Methodology

Although agriculture is the most important sector in China economy and food self-sufficiency is the primary concern of its policymakers, quantitative research in Chinese agriculture is very limited. Only after 1978 did Chinese researchers begin to develop formal models of Chinese agriculture.[11]

The lack of a comprehensive and agreed-upon theory of producer and consumer behaviour under China's centrally planned economic system represents an enormous impediment to quantitative research on China's agricultural production. Most models that have been built for output projection and the selection of farming structure are direct applications of western analytical techniques to Chinese agriculture. Among these studies are the input-output models of the Chinese agricultural sector of 1982 (Chen et al., 1985), the multi-objective mathematical programming model of grain production (Chen et al., 1983), the large scale linear programming model of grain and cash crops for the year 2000 (Grain and Cash Crops Development Research Group, Chinese Academy of Agricultural Science, 1985).

It is also common to use input and output indices derived from profit or cost functions to estimate supply and demand functions. Related studies can be found in T.J. Coelli (1996) and of

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[11]Chen and Buckwell (1991;54)

L. Wong (1989). In Coelli's study on the measurement of total factor productivity growth in Western Australian Agriculture, the author constructed the Tornqvist index[12] (Tornqvist, 1936) of three output groups (crops, sheep products and others) and five input groups (livestock, materials and services, labor, capital, and land). These input and output indices are then used in the estimation of output supply and input demand equations derived from a flexible profit function. In Wong's study on agricultural productivity in China and India, the trends in agricultural productivity growth in China and India were examined. The research compared the rate of change in productivity and ascertained the contributions of land, labor, livestock, machinery, fertilizer, technology and productivity growth.[13] The results in Wong's paper indicate strong upward trends in labor productivity and land productivity, but technical change made little net contribution to agricultural productivity growth. Relevant research on agriculture production and output projection for countries other than China can be found in the studies of the OECD (1995), the World Bank (1985), and Brown (1995). Some of the assumptions and results of these studies will be chosen as the basis for the paper's projection in Section 3.5.

The modelling techniques developed in the West and applied in China's agriculture can be roughly classified as belonging to one of the five approaches: programming models, simulation, decision rules, single aggregated production function, and supply response analysis.

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[12] The Tronqvist index can be shown to be a derivative of the homogeneous translog production function, which provides a second-order approximation to an arbitrary production function at any given point (Christensen et al., 1973).

[13] The mathematical expression for the total productivity index with five factor inputs in Wong's paper is as follows: $\Delta A/A = \Delta(Y/N)/(Y/N) - W_1\, \Delta(L/N)/(L/N) + W_2\, \Delta(F/N)/(F/N) + W_3\, \Delta(M/N)/(M/N) + W_4\, \Delta(S/N)/(S/N)$, where A: shift factor of production; W_i : factor share of corresponding factor; Y: output; N: labor; L: land; F: fertilizer; M: machinery; and S: livestock.

However, the challenge is to find which of these techniques can be applied to China. With the limited data available to researchers, the doubt about the accuracy and other special properties of the data for Chinese agriculture, those techniques that involve optimization and a large number of variables may not be appropriate to grain production in China. The approaches of single production function and supply response analysis seem to have produced more reliable projections of grain output in the past. In this paper, the microeconomic foundations of the five modelling techniques will be discussed first. The proposed aggregate production function estimation and supply response analysis will next be presented in details in Sections 3.3 and 3.4.

Programming Models

Programming models[14], in various forms, can be used at the sectoral, regional, and national levels. A large scale programming model is a powerful tool, especially for structural and policy impact analysis. The technique is used in finding solutions to various farm management problems and in planning the farm enterprises mix by mathematically determining the optimum combinations of enterprises or inputs in order to maximize the profit or minimize the cost within the constraints of variable resources (see also Hazell and Norton, 1986). However, there are certain theoretical drawbacks in the programming approach which make it inadequate for analyzing Chinese grain production. First, this method, which typically uses linear programming models, is often used to find optimum or profit-maximizing outputs at different levels of factor or product price. These profit-maximization or cost-minimization approaches are acceptable for commercial producers in developed countries; however, they are less applicable to self-subsistence grain producers in developing countries like China because grain production is for

[14]A.A. Rane (1983)

self-consumption instead of for sale. Second, the data required in this approach, such as input and output prices, are either unavailable or distorted in China. Also, since China is such a large country with complicated farming systems that are still not market-oriented, a very large number of representative farms or regions would be necessary to cope with the whole sector adequately. This would create an immense computational task. Third, the impact of policy changes on agriculture will take many years to work through. Since the main purpose of this paper is to find out a suitable model for aggregate analysis and projection, a static programming model using cross-sectional data is not desirable. A large scale, dynamic programming model might remedy some of these shortcomings inherent in a static model. However, such an approach is, in many cases, impossible due to resource constraints.

Simulation

Simulation modelling was considered as a useful tool in developing countries for assessing the possible impacts of adjustments used in agricultural structures and policies. However, this approach is no longer popular mainly because of the lack of knowledge of the effects of qualitative factors and the inability to quantify many interrelationships of agricultural economic systems, which makes the specification of the appropriate functional relations and the estimation of the relevant parameters difficult. Technically speaking, simulation modelling requires interdisciplinary research and both cross-sectional and time-series data are needed for building a simulation model, which requires much computing time and other resources.

Decision Rules

Unlike other approaches, decision rules intend to help planners make better production decisions under risk and uncertainty. The simplest representation for this approach can be shown with the help of the following example. The hypothetical payoff matrix involves five different production strategies -M, N, O, P, Q -whose outcomes under three different states of nature -X, Y and Z -are given in Table 3.1. X, Y and Z represent natural factors such as natural disasters, weather conditions, insect pest attacks, and political and market conditions.

Table 3.1 Payoff Matrix for Decision Rules Technique

Strategies	Natural States		
	X	Y	Z
M	20	20	20
N	4	64	14
O	15	15	54
P	44	16	29
Q	19	39	29

Based on this pay-off matrix, different decisions will be made according to different criteria. For instance, with the Maximin decision rule, a pessimistic or highly risk-averse decision maker will choose strategy M that gives the highest worst payoff as 20. A risk-loving planner will select strategy N that gives the maximum of maximum outcome as 64. With the Laplace (Bayes) criterion, the states of nature are assigned equal probabilities and the decision is made based on expected pay off, so that strategy P will be chosen with its highest expected payoff of 29.67[15].

There are also other decision rules such as Minimax-Regret and Hurwicz Optimizm-

[15]The payoffs for strategy M, N, O, and Q can be shown as 20, 27.33, 28, and 29 respectively.

Pessimism Criterion which can be used in analysis on agricultural production. Also, game theory is applicable to situations that involve conflicting interests and in which the outcome is determined by each players' strategies. Both pure strategies and mixed strategies can be applied to several decision-making problems in the farming business, such as what type of farming should be adopted, purchasing or renting of land, the amount to be borrowed for production, and the like. In particular, the household contract system of current grain production in China can be represented by a dynamic game that involves the government as the owner of the land and the representative household in a finite time horizon. Hence, the government is considered as the leader and farmers as followers so that where a sub-game equilibrium can be derived. Although decision rules and game theory models have not yet been used very often in agricultural economic research, it can be an appealing and feasible tool with the combination of other techniques.

Most contemporary studies are based on the theory of profit-maximizing behavior of producers and utility maximizing of consumers under the operation of the market mechanism that may or may not be interfered with by governments. More complicated techniques involve optimal control processes over a finite or infinite time horizon. However, in applying such techniques to China's grain production, many important assumptions are inappropriate and certain data are unavailable. Therefore, the desired approaches should be both theoretically sound and pragmatic in nature.

<u>The Aggregate Production Function and The Supply Response Approaches</u>

The fourth and fifth approaches, namely aggregate production function and supply response analysis techniques, both based on econometric techniques, have demonstrated their superiority in modelling the grain production function in China. The availability of time-series data makes it possible to estimate the aggregate grain production function and the supply response function. Furthermore, these approaches are particular suited to analyzing trends and broader features of the agriculture sector as well as the impact of government policies on this sector.

3.2 Assessment of the statistical data and variable explanation

3.2.1 Statistical data on grain production in China 1952-1993

Reliable data are very essential for any quantitative analysis. However, studies on grain production of China have always been troubled by data availability, accuracy, and consistency. Besides the State Statistical Bureau of the People's Republic of China (SSB), other sources outside China include the United States, where figures are collected by the Central Intelligence Agency (CIA), the Department of Agriculture (USDA), and the Department of Commerce (DOC). The major international sources involve international organizations like the Food and Agriculture Organization of the United Nations (FAO) and the World Bank. In this study, it is desirable to have enough data to undertake a time-series analysis. However, the official statistics of China were not available to foreign researchers for approximately two decades from the late 1950s. Thus, this study is generally based on the data supplied by the Chinese statistical authorities, though some forecasting figures from international organizations will be introduced for comparison purposes. Because the State Statistical Bureau of the People's Republic of China was founded in early 1950s, this study will be conducted from year 1952 instead of year 1949, when the Communist Party came into power in China.

The data-collecting system in China's agriculture sector has been designed to provide information for a centralized planning system. Hence, there are few problems of sampling bias. Instead, the major non-sampling errors have come from reporting bias, which requires caution in interpreting the empirical results. Taking grain output data as an example, there was a tendency towards over-reporting by local officials in order to create political advantage. On the other hand, since state quotas were based on the production level achieved in the year before, there was an incentive to under-report grain output so as to both maintain the quotas of next year at a lower level and retain more grain for financial advantage. Therefore, it is difficult to assess the size of the reporting bias for not only did it change from time to time, but also it differed greatly across regions. Nevertheless, it is considered that data from the Chinese statistical authorities are more reliable than those compiled by other institutions as well as similar data for some other developing countries (Stone, 1982). Hence, this study uses published statistics from the Chinese statistical authorities and the computation results can easily be adjusted if more reliable data become available.

Another issue concerns the consistency of grain production data over time. For instance, during the periods of political movements like the Great Leap Forward (1959-61) and the Cultural Revolution (1966-77), the statistical system was badly influenced like everything else. As a result, many detailed statistical materials were either not collected or modified for political purposes. In 1978, since the switch in policy to the household responsibility system, the former reporting system with the production team and the commune as the basic information provider was replaced by a sampling survey system with household as the basic unit of production. It is generally agreed that data on agricultural production were of the better quality than those on consumption; figures for grain are generally better than those for vegetables and livestock production; statistics on output are more accurate than those on yield; and total sown area is considered more reliable than the arable land data. (Fan, 1990). The general assessment directly influences the choice of variables and model specification in this study. Further study can be conducted by estimating the proposed models with data since 1978 to compare the results between two different lengths of time-series data.

3.2.2 Variables

The basic forms of proposed models can be expressed as:

(13) $LnG = b_0 + b_1 LnL + b_2 LnS + b_3 LnM + b_4 LnI + b_5 LnF + b_6 T + \epsilon,$

(16) $LnG = \beta_0 + \beta_1 T + \beta_2 LnS + \beta_3 Pg + \beta_4 Pgf + \beta_5 Pgf + \beta_6 LnW + \beta_7 D1 + \beta_8 D2 + \beta_9 D3 + \beta_{10} D4 + \beta_{11} D5 + \beta_{12} D6 + \epsilon,$

before the interpretation of the models is discussed, the variables involved in the equations are introduced as follows:

G: Grain output (million tonnes). In China, grain includes rice, wheat, coarse grains, tubers and legumes. In China's official statistics, grain output is measured in unmilled grain. Grain output is the product of yield and total growing land. However, growth in yield has frequently been taken as a major indicator of political achievement. Therefore, the data for yield and growing area are somehow less accurate than those of grain total output and total sown area.

T: Time trend variable for technological improvement

S: Total sown areas (ha). Total sown areas, which served as the land input, is the sum of sown areas and pasture. It is generally agreed that the arable land and growing area data are extremely inaccurate[16], therefore, the data of total sown areas are used in this study.

L: Total labor force in agriculture. In this study, we measure labor input in agriculture in stock terms. It is measured in persons at the end of the year. One should be aware that because in China land and other inputs are scarce whereas labor is abundant, the actual labor contribution to grain output is not necessarily the total labor force in agriculture, the only variable for which data are available. Instead, efficient labor input would be a more suitable variable, but unfortunately it is hard to measure the quantity of efficient labor force. As a result, many previous studies on agriculture have not included the labor as an input, and it is expected in this study that the total labor input will not be significant to aggregate grain output.

M: Machinery input (energy input). It is measured by the total power of agricultural machinery (million kw). The data are collected based on the total horsepower at the end of each year.

I: Total irrigated areas (ha). This input is regarded as the representative of the rural infrastructure, which is referring to effective areas with water sources and irrigation equipments and which can be irrigated in a normal year.

F: Fertilizer. This study includes chemical fertilizer as the input measured by pure nutrient.

Pg: Grain purchasing price (Wang keming, 1988). The Index of grain purchasing price (1978=100) is used for the aggregate supply analysis. It refers to the weighted average of quota price, above-quota premium, and negotiated price. As the official grain purchases constituted an overwhelming part of the total grain traded during the last three decades, and since reliable, comprehensive time-series data for the prices on the free market is not available and, therefore, these prices were not taken into consideration.

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[16]Fan (1990).

Pgc: Ratio of the purchasing price of grain over cotton

Pgf: Ratio of the purchasing price of grain over the selling price of chemical fertilizer

W: Sown areas suffering from natural disaster (indicator changes in weather and natural state)

D1-D6: Dummy variables for different policy eras, D1=1 for 1959-61; D2=1 for 1962-65; D3=1 for 1966-77; D4=1 for 1978-84; D5=1 for 1985-88; D6=1 for 1989-93. (OECD 1995, Chen & Buckwell, 1991 and Cheng, 1994)

3.3 Aggregate Production Function Method

3.3.1 The Forms of the Aggregate Production Function: the interpretation of coefficients and characteristics

Some early studies on the aggregate production function in agriculture have been carried out by Harris (1991), Gilland (1979), and Strout (1979). A simple version of the aggregate production function in agriculture can be found in the study of Alan Strout (1979), who has estimated a production function of the following form:

(1) $Q = b_1 L + b_2 F + b_3 I,$

where Q is total cereal output, F is fertilizer, L total cropland and I irrigated area. Q and F are in metric tonnes and L and I in hectares. Harris (1991) introduced the erosion factor and the production function becomes:

(2) $Y = (1\text{-}e)b_1 + b_2 f + b_3 I,$

where Y is yield which is equal to Q/L, f is F/L and I = i/L. Since soils can be degraded by erosion or built up overtime, which implies that the average quality of cropland can change, the parameter e was introduced to represent the yield loss from degradation by erosion in this model.

In its most general form, the aggregate production function can be mathematically expressed as follows:

(3) $Y = f(X_1, X_2, \ldots \ldots X_n, T)$,

where Y stands for output such as the crop, T represents time, and $X_1, X_2, \ldots \ldots X_n$ refer to inputs. The following translog production function is a more specialized form of Equation (3):

(4) $Ln(Y) = b_0 + b_t t + \sum_i b_i Ln(Xi) + \sum_i b_{it} Ln(X_i) t + \sum_i \sum_j b_{ij} Ln(X_i) Ln(X_j) + b_{tt} t^2$

The following constraints are expected to be held based on the theoretical hypotheses:

(5) $\sum_i b_i = 1$

(6) $\sum_i b_{ij} = 0$; for all j;

(7) $\sum_i b_{it} = 0$.

If all inputs are mutually separable, but each input cannot be separated from technical progress, then the aggregate production function can be expressed as:

(8) $Y = f[g_1(X_1, T), g_2(X_2, T) \ldots g_n(X_n, T)]$.

The theoretical justification for this form is that the quality of each input varies over time whereas the effects among inputs are indirect over time. If all inputs and time are separable, we may express the production function as:

(9) $Y = f[g_1(X_1), g_2(X_2) \ldots \ldots g_n(X_n), T]$.

Other widely-used functional forms, such as the linear form (10) and the quadratic production function form (11) serve different purposes in research on agriculture production:

(10) $Y = b_0 + b_1 X_1 + b_2 X_2 \ldots \ldots + b_n X_n$

(11) $Y = b_0 + b_1X_1 + b_2X_2 - b_3X_1^2 - b_4X_2^2 + b_5X_1X_2 + \ldots \ldots$

In practice, to select a particular form of production function for a particular set of input and output data, researchers usually adopt the following criteria. First, the functional form should contain no more parameters than are necessary. Second, a clear economic interpretation and functional structure are required for the parameters. Third, the chosen functional form should be well behaved and should be consistent with the maintained hypotheses[17] (Fuss and McFadden, 1978).

In this paper, the Cobb-Douglas form of the aggregate production function is adopted for China's agriculture sector. The Cobb-Douglas production function has been favored by Chinese scholars because of its simplicity and transparent economic implications. Before the introduction of the household responsibility system in grain production in 1978, the leader of the production team made decisions on the use of available inputs and outputs primarily to fulfill government targets and secondly, to maximize profits. Since 1978, farmers have made their decisions on inputs and outputs on the basis of maximizing profits after fulfilling the quotas contracted with the government. With the assumption that all basic production units in China have potential access to the same technology, the Cobb-Douglas production function is a reasonable form. More importantly, the Cobb-Douglas function seems to be the most desirable form for forecasting grain output in China. It is noted that the use of any single production function leads to some problems with aggregate data. Also, a Cobb-Douglas production function has a constant elasticity of substitution. These defects have led researchers to introduce more general forms, such as the

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[17]Other theoretical criteria for the choice of the production function form can be found in Rane (1983).

translog, the general quadratic, the general Leontief, and the Box-Cox forms[18].

3.3.2. Proposed forms for estimation

The proposed Cobb-Douglas aggregate production for China's grain production can be represented as follows[19]:

(12) $G(t) = A(L(t)^{b1})\,(S(t)^{b2})\,(M(t)^{b3})\,(I(t)^{b4})\,(F(t)^{b5})\,e^{b6*t}\,e^{\epsilon(t)}.$

The notation is standard: G is grain output, L labor force, S total sown area for grain production, M machinery, I irrigated area, F fertilizer input, t a time trend and ϵ the random error term.

The logarithm form of this aggregate production function is that as follows:

(13) $LnG = b_0 + b_1\,LnL + b_2\,LnS + b_3\,LnM + b_4\,LnI + b_5\,LnF + b_6\,T + \epsilon,$

where the parameter associated with the time trend reflects the assumption that technology improves over time exponentially (other assumptions about the form of technology improvement will also be tested for the purpose of comparison).

It is expected that all the inputs will be positively related to grain output and that constant return to the scale will be observed. The restriction for a linear-homogeneous production function above is as follows: $\sum_i b_i = 1$ (i=1, 2, ...6). However, it is observed that the grain output in China demonstrated an unsmooth time path and since the Cobb-Douglas production function does not include short term factors such as policy, natural conditions, etc., the partial correlation between output and certain variables may have negative signs so as to statistically match the zigzag

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[18] A good summary of various approaches was made by Lovell and Schmidt in 1988, and more specific analysis on China's agriculture was introduced by Fan (1990).

[19] See also Zellner, A., J. Kmenta and J. Dreze (1966), *Econometrica.* **34**, 784-795.

growth path of grain output, which is not the case in reality. Short-term factors will be considered in a supply response model in the next section and the Error-Correction Model (ECM) introduced in Section 3.5 and Appendix B.

The Cobb-Douglas production form adopted in this study, assumes all inputs and time to be separable. Its general functional forn. is that as follows:

(14) $\quad Ln(Y) = b_0 + \sum_i b_i Ln(Xi) + b_t T + \sum_i b_{it} Ln(Xi)\, T + b_{tt} T^2,$

where the theoretical background of this form is the fact that every input change over time whereas the effects among inputs are indirect through time. Ln(Xi)T represent the cross term of every input and time trend.

3.3.3 Interpretation and empirical results

The following equations have been estimated and the results are presented in Table 3.2.

(3.1) $\quad LnG = b_0 + b_1 LnL + b_2 LnS + b_3 LnM + b_4 LnI + b_5 LnF + b_6 T + \epsilon$

(3.2) $\quad LnG = b_0 + b_2 LnS + b_3 LnM + b_5 LnF + b_6 T + \epsilon$

(3.3) $\quad LnG = b_0 + \sum_i b_i Ln(Xi) + b_t T + \sum_i b_{it} Ln(Xi)\, T + b_{tt} T^2 + \epsilon.$

Some results from previous studies are not satisfactory. For instance, in Fan's study (1990), the coefficients of machinery and irrigation inputs are both insignificant and the coefficient of draft animals (as one of the capital inputs) is negative, whereas in Lau and Yutopoulous (1987) land input is not significant.

The results from the single aggregate production function can be summarized as follows. First, the Cobb-Douglas form is used for Equation 3.1 where the inputs for grain production are labor, land, machinery, fertilizer, and irrigation. The time trend measures the technical change

Table 3.2 Estimation of the Cobb-Douglas Production Function

Equation	3.1	3.2	3.3	Fan(1991)[20]	H-R(1985)[21]
Observations:	42	42	42	406	43
Constant	-0.752	-1.7878	-2.9618	-0.132	0.318
	(-0.1579)	(-0.3879)	(-0.3269)	(-5.13)	(3.74)
X1(L)	-0.277		-0.61775	0.278	0.562
	(-1.412)		(-1.698)	(7.19)	(5.45)
X2(S)	1.409	0.97842	0.82888	0.356	-0.065
	(2.505)	(2.494)	(1.095)	(7.88)	(-1.03)
X3(M)	-0.188	-0.22316	-0.28124	0.055	0.136
	(-2.771)	(-5.447)	(-2.523)	(1.77)	(2.57)
X4(I)	-0.480		1.2320	0.059	
	(-0.9495)		(1.100)	(1.81)	
X5(F)	0.347	0.28331	0.22399	0.426	0.089
	(4.232)	(4.141)	(1.215)	(7.01)	(3.74)
X6(T)	0.032	0.0302	0.18408	0.0123	
	(6.641)	(6.675)	(0.4317)	(2.41)	
X1t			0.024774		
			(0.8601)		
X2t			-0.015635		
			(-0.3898)		
X3t			0.0090387		
			(1.372)		
X4t			-0.040235		
			(-1.074)		
X5t			0.0082815		
			(0.6211)		
Xtt (T^2)			-0.0013173		
			(-2.349)		
Adjusted R^2	0.96	0.96	0.98	N/A	N/A
Sum of Coef.	0.843	1.06877	----	1.042	1.04
Ho: $\sum_i b_i = 1$	(-0.3815)	(0.17790)		N/A	N/A

Note: 1. T-ratios are in parentheses. t(d.f.=37;95%)=2.02; F(d.f=1,37;95%)=4.09&(99%)=7.30.
2. X1: Labor; X2: Land; X3: Machinery; X4: Fertilizer; X5: Irrigated area, Xit: cross terms of every input and time trend.
3. The production elasticity for input I in this function form is $\partial \ln Y/\partial \ln Xi = b0 + bit*T$. Therefore, if bit > 0, production elasticity of input i is increasing, implying input i using.

[20] Both Fan (1990) and Hayami-Ruttan (1985) used the OLS method. Fan used panel data. They included Livestock input besides other inputs in this study. The estimated coefficient for livestock inputs in their studies is shown in place of the constant term in Table 3.2.

over time. Except for the variables of labor and irrigation, the coefficients are significant at the 95% level, which is in accordance with what was expected.

Second, the production elasticity of land is much larger compared with other inputs, which indicates that land inputs still dominate China's grain production and contribute the largest share to the output. The chemical fertilizer input has played an important role in production whereas the contribution of irrigation to grain production is insignificant. The negative coefficient of machinery input is not the case in reality, which is due to the limitation of the proposed functional forms. Similar results have been obtained by previous researchers.

Third, the significance and positive sign of the time trend coefficient strongly suggest that of technological improvement contributes to grain production in an exponential form and confirms the existence of technical change in China's agriculture.

Fourth, the hypothesis of CRTS (constant-returns-to-scale) for grain production in China cannot be rejected at the 99% level of confidence, a fact that supports the validity of the Cobb-Douglas production function. Therefore, the results derived from Equation 3.2 will be used as the basis for projection in Section 3.5.

Fifth, Equation 3.3 includes the same inputs as those for Equation 3.1. In addition, the cross term of each input and time trend is used to catch the relative changes of each input in total input over time. The insignificance of some important inputs like land implies possible econometric estimation problems such as multicollinearity. Therefore, this more general production functional forms will not be chosen later in this study for forecasting China's grain output in the future even though forecasting may still be valid under multicollinearity problems.

In general, the results obtained here are comparable to those obtained by other researchers. It should be noted that most of the previous studies on agricultural production also employed the Cobb-Douglas production function form. Fan (1990) used panel data to estimate the production function for China for the period of 1965-86. Hayami and Ruttan (1985) estimated production functions for developed countries without considering technical change over time. As for Lau and Yotopoulous (1987), they chose a translog form, based on the first difference data and the same data set used by Hayami and Ruttan(1985). The production elasticity for livestock is negative in Fan's studies whereas in Lau and Yotopoulous (1987), the coefficient is negative for land input, which is not the case in reality. The machinery and irrigation inputs are not significant in Fan's studies while land input is insignificant in H-R's estimations. Thus, the results of this study do not differ significantly from those obtained by previous researchers, whereas similar defects exist, namely at least one input has a negative production elasticity and some inputs have insignificant coefficients.

It is worthwhile to point out that most researchers have overlooked the possibility of spurious regression, namely the high R^2 is a result from similar time trends between input and output variables rather than a result from explanatory power. Therefore, a time-series analysis has been conducted in order to prevent spurious regression, and the results are shown in Appendix B. From the time-series analysis, we concluded that although all variables in the model are non-stationary time series, their first difference data can be cointegrated. Therefore, the C-D production function can be considered to reflect the long-run relations between inputs and grain output, and the proposed functional forms are not improper for forecasting purposes. In order to improve the model by including short-run effects to grain production in China, one may use ECM (Error-Correction-Model) or conduct supply response analysis. Since the latter method involves transparent economic interpretation, supply response analysis is introduced in the following studies.

In summary, the general results in this study are in accordance with what we expected and Equation 3.2 will be chosen to forecast the grain production in Section 3.5. Machinery input has a negative production elasticity [21], which is possibly not the case in practice, for the reason that the Cobb-Douglas production functional form cannot include short-run factors such as policy and the state of nature.

3.4 Supply Response Analysis

3.4.1 Model and Variables

From the single aggregate production function estimation, we can draw the conclusion that the grain output of China can be well explained by certain inputs, such as technological improvement, total sown areas, labor input, machinery, chemical fertilizer, irrigation, and so on. However, it is also observed that the growth course of grain output in China shows an erratic path which indicates that certain short-run factors as well as long-run ones should also be considered. In China, especially prior to 1978, pricing and other state policies exert a crucial impact on the grain output. Therefore, an approach to integrate these factors and test certain hypotheses is desirable.

The objective of research on changes in agricultural supply is to understand better the mechanism of supply response, to prescribe solutions to problems found in the study on the past,

[21] The simple correlation between machinery input and grain output in China (1952-93) is positive with value 0.7.

and to improve the ability to forecast supply changes in the future. "Agricultural supply response analysis" is defined by Colman (1983, 201) as:

> "The art of estimating the quantitative supply response of agricultural commodities to changes in product prices, input prices and other relevant measurable aspects of the changing environment for agricultural production."

The conventional specification of a supply response function is rooted in neoclassical economic theory which is based on the profit-maximizing behaviour of producers under the operation of the market mechanism. Research on supply response analysis has been conducted by the FAO (1971), Colman (1972 and 1983), Chen and Buckwell (1991). For instance, Colman (1972, 49-51) studied the supply response of cereals in England using a specification that can be simplified as follows:

(15) $Ait = f(P_{it}, P_{kt}, P_{nt}, Y_{it}, U_t)$,

where A represents area harvested, P_{it} the price per unit of output at period t, P_{kt} the price per unit of the alternative agricultural products at, P_{nt} the price per unit of input, Y_{it} the yield per hectare and U_t the disturbance term. This model is based on the theory of the neoclassical firm in a market economy. Profit maximization is assumed to be the aim of the producers. This suggests that the market prices of the output, competitive crops and agricultural inputs are the three major signals for producers in their decisions on production. This general specification also incorporates the uncertain nature of agricultural production, such as the influence of the weather. The last element to be pointed out is that the prices here for each year are in fact the expected prices for the next year.

3.4.2. Proposed forms for grain production in China

To apply this approach to China in the context of this paper, certain modifications have been made. First, it is more sensible to use grain output rather than sown area as the dependent variable in this study. Besides, sown area can be misleading if used as the dependent variable because of a declining trend in sown area. Second, as mentioned before, government policy has played an essential and direct role in controlling the production and industrial inputs, both in quantity and prices. Thus, the policy factors are included explicitly in the following model. Finally, one special feature of China's grain production is that approximately three quarters of the grain produced in China is for peasant farmers' self-subsistence rather than for sale. This feature is due not only to the weakness in the social infrastructure but also to China's compulsory purchasing and centralized distribution system. Therefore, self-subsistence is an important factor influencing farmers' supply response behaviour and will play a key role in explaining some empirical results of this study. Based on the above-mentioned reasons and the analysis in Section 3.3, the single supply response function for China's grain production can be represented as follows:

(16) $$LnG = \beta_0 + \beta_1 T + \beta_2 LnS + \beta_3 Pg + \beta_4 Pgf + \beta_5 Pgf + \beta_6 LnW + \beta_7 D1 + \beta_8 D2 + \beta_9 D3 + \beta_{10} D4 + \beta_{11} D5 + \beta_{12} D6 + \epsilon,$$

where G is grain output; Tis time trend variable for technological improvement; S is total sown area; L is total labor force in agriculture; M is total power of agricultural machinery; I is total irrigated area; Pg is grain purchasing price; Pgc is the price ratio of purchasing price of grain over cotton; Pgf: is the price ratio of purchasing price of grain over selling price of chemical fertilizer[22]; Wis sown areas suffering from natural disaster (indicator changes in weather and natural state); D1-D6 are dummy variables for different policy eras, D1=1 for 1959-61, D2=1 for 1962-65, D3=1 for 1966-77, D4=1 for 1978-84, D5=1 for 1985-88, D6=1 for 1989-93.[23] Government policies are assumed to be exogenous in all proposed supply response functions, although certain degree of endogenetic property could exist for some periods.

For Equation (16), the terms involving the time trend and the total sown area for grain represent the long term relations between input and output in grain production whereas other terms capture the income/substitution effects and policy influence on grain output in the short run. Relevant elasticities can be compared in order to analyze both the short run and long run effects.

3.4.3. Interpretation and empirical results

The grain output response model is specified as a function of two major components, namely the long-run trend variables and short-run random variables. Trend variables include sown land, fertilizer, machinery, and technological improvement, while random variables are represented by the state of nature and government policies including grain purchasing price, price ratios, and dummy variables.

Compared with the study in Chen and Buckwell (1991), this paper added the variables L, M, I and extended the period from 1952-84 to 1952-93 with relevant policy dummy variables.

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[22]For Chinese grain production as a whole, the main competitive crop is cotton and the major industrial input is chemical fertilizer.

[23]For the details of the choice of dummy variables, see Allan & Chen (1991) and OECD (1995).

Sown area was used instead of growing areas in previous work since there is evidence that the statistics for sown areas in China is more accurate than those for growing areas.[24] Basic interpretation and intended results such as the signs of the parameters are in line with previous studies.

The long-run input variables are expected to maintain the same sign as those obtained in Section 3.3, while for the short-run factors, the area suffering from natural disasters is chosen as the indicator for changes in the state of nature. Annual grain production in China is expected to be negatively affected by this indicator. It is practical to use the index of areas suffering from natural disasters to represent the changes in natural environment and the negative relationship between the nature indicator and grain output seems to be obvious. However, it should be noted that the Chinese authorities tended to overstate the true effects of natural disaster when grain output decreased. Therefore, the magnitude of the coefficient could be biased.

Meanwhile, grain purchasing price and price ratios between grain/cotton and grain/fertilizer will be considered as other short run factors, together with the shifts in policy patterns in China. Because the markets for agricultural products and fertilizer in China were controlled by the official marketing system, the purchasing price for grain and prices ratios are stipulated by the government and, therefore, the supply response mechanism for China's grain production is fundamentally different from that of a market economy. It is observed that when Policy Pattern A was adopted, a significant increase in grain purchasing price was offered. At the same time, the prices for other major agricultural and industrial products also climbed. However, when Policy Pattern B was pursued, a general stagnation in prices was recorded. As a result, it is

[24]Fan (1991)

expected that a positive relationship exists between grain purchasing price and production. The movement of the price ratios associated with policy shifts has a double effect on grain production. On the one hand, higher price ratios favor grain production in China because of substitution and income effects. On the other hand, when taking a corresponding policy pattern into consideration, higher price ratios, which behaved as proxy variables of regulatory climates, would be manipulated against grain production. More specifically, when Policy Pattern A, which stressed balanced development and diversified development strategy for the agricultural sector, was adopted, the two price ratios fell because of the faster increase in cotton and fertilizer prices, which would have a positive impact on grain output. When Policy Pattern B was adopted, these two price ratios increased, which led to a decline in grain output. Therefore, grain production in China is hypothesized to be positively related to Policy Patten A but negatively related to Policy Pattern B and the price ratios of grain/cotton and grain/fertilizer.

Among the equations shown in Table 3.3, Equation 4.1 is the restricted one, which assumes government policies will not directly affect grain output, and other equations are unrestricted. As shown by Equations 4.1, 4.2, 4.3, 4.4 and 4.5, grain production responds to all the proposed factors in the directions hypothesized. In other words, grain output responds positively to all the long-run factors (except for machinery input) and its purchasing price. On the other hand, grain output responds negatively to changes in grain/cotton and grain/fertilizer price ratios and the natural disaster indicator. Furthermore, although the signs of the coefficients of the dummy variables in Equations 4.2, 4.3, 4.4 and 4.5 are as expected, they are basically not significant when both price factors and policy pattern variables are included at the same time (Equation 4.3). When only the dummy variables for Policy Pattern B are included in Equation

Table 3.3 Aggregate Supply Response

Equation	4.1	4.2	4.3	4.4	4.5
Observations:	42	42	42	42	42
Intercept	-5.2481	-7.7812	-5.3312	-5.9238	-4.5587
	(-1.12)	(-1.59)	(-1.22)	(-1.271)	(-1.049)
T: Time trend	0.0421	0.0364	0.0400	0.0373	0.0373
	(10.24)	(12.51)	(5.65)	(17.70)	(7.68)
S: Land	1.2806	1.4919	1.4087	1.3793	1.267
	(3.24)	(3.61)	(3.87)	(3.414)	(3.37)
M: Machinery			-0.1403		-0.1211
			(-2.15)		(-2.55)
F: Fertilizer			0.1510		0.1401
			(2.25)		(1.86)

W: Area suffering from natural disasters	-0.08983	-0.08657	-0.1021	-0.1125	-0.1005
	(-3.85)	(-3.44)	(-4.59)	(-3.31)	(-3.16)
Pg: Grain purchasing Price	0.0343	0.0719	0.0727		
	(2.48)	(3.001)	(2.53)		
Pg/Pc: Grain/Cotton Price ratio	-0.2946	-0.44337	-0.0160	-0.2706	-0.1737
	(-2.47)	(-4.76)	(-2.14)	(-2.742)	(-2.76)
Pg/Pf: Grain/Fertilizer Price ratio	-1.7804		-0.177		
	(-1.83)		(-1.36)		
D1: 1958-60		-0.0072	-0.0725	-0.07873	-0.0143
		(-0.56)	(-0.75)	(-1.60)	(-0.27)
D2: 1961-66			0.0158		
			(0.21)		
D3: 1967-77			-0.0806	-0.0881	-0.0519
			(-0.61)	(-2.63)	(-1.05)
D4: 1978-83			0.021		
			(0.15)		
D5: 1984-88			0.0961		
			(0.61)		
D6: 1989-93			0.0600		
			(0.35)		
Adjusted $\underline{R}^2$	0.96	0.96	0.98	0.97	0.97
DW	1.154	1.005	2.143	1.251	1.118

Note: 1. T-ratios are in parentheses; t(d.f.=37;95%)=2.02; d_L (n=40,k'=6;99%)=0.997, d_U(n=40,k'=6;99%)=1.652; d_L(n=40,k'=8;99%)=0.895, d_U(n=40,k'=8;99%)=1.799; d_L(n=40,k'=14;99%)=0.597 d_U(n=40,k'=14;99%)=2.297.

2. Log values for all variables are used for estimation except for dummy variables and time trend.

4.4, the negative relationship between Policy Pattern B and grain output tends to be significant as anticipated. These results indicate that since the price ratios worked well as indicators for the shifts in policy patterns, the effects of tl e policy dummy variables are mostly absorbed by the price ratio indicators. In other words, apart from the effects of the two price ratios which were included to illustrate the shifts in policy patterns, there was no significant difference in policy effects on grain supply among different periods.

3.5 Projections for grain output and scenario analysis of the potential for self-sufficiency

It is apparent that the complexities of grain production in China cannot be encompassed fully by relatively simple quantitative analysis. Nevertheless, the projections based on the models proposed in this study, which integrated the major factors related to grain production, are expected to be more reliable because most previous studies have only taken the trend of grain output itself into consideration. In this section, the Equations 3.3 and 4.4 will be chosen for forecasting purposes based on their better statistical results. Meanwhile, the error correction model proposed by my previous study will also be presented for comparison purposes. Relevant studies concerning grain production projections in China can be found in the OECD (1985, 1995), Brown (1995), Chen & Buckwell (1991), in most of which forecasts were simply based on the trend in grain output development.

Table 3.4 presents a forecasting power comparison among the different models for the years 1991-1993 based on different criteria. According to Table 3.4, it still requires careful judgement to determine which model demonstrates superior forecasting power. Based on the criteria of Theil Inequality Coefficient U and Mean Square Errors, Vector Autoregression (VAR) models seem to have the best forecasting power, however, if the Adjusted R^2 and the R^2 between observed and predicted grain output are examined, models 3.2 and 4.4 seem to be more powerful. It should be noted that the ECM model, which has shown the best forecasting power in my previous study (1996) according to M.S.E. (Mean Square Error) criterion, has shorter sample period than the rest of the models. The fitness of the forecasts within the sample period for the first four models is presented graphically in Figure 1 to 4.

Table 3.4 Forecasting power comparison

Model	Adjusted R^2	Theil Inequality Coefficient U	M.S.E	R^2 between observed and predicted grain output
Equation 3.2	0.9736	1.124	0.0016834	0.4383
Equation 4.4	0.9673	3.104	0.0055287	0.9997
VAR(LG,2)[25]	0.9676	0.290	0.0007719	0.236
VAR(LG,2;LS,2)	0.8639	0.246	0.0008620	0.177
ECM Model[28]	0.1753	0.402	0.00064841	0.5877

Note: Forecasts for the first four models are within the sample period 1952-93 (from observation No.2 to 42), whereas within period 1978-93 for ECM Model.

[25]In order to get better forecasting results, several VAR models were introduced which turned out that the regression of LG_T on LG_{T-1} and LG_{T-2}, and the regression of LG_T on LG_{T-1}, LG_{T-2} and LS_{T-1} , LS_{T-2} (Land inputs which demonstrated the highest production elasticities in all proposed models in this study) had the better forecasting power. For comparison purposes as well, the results of ECM (Error-correction Model) from my previous study (1996) were presented. Related explanation regarding the ECM model can be found in Appendix B.

Figure 1: Simulation for Equation 3.2

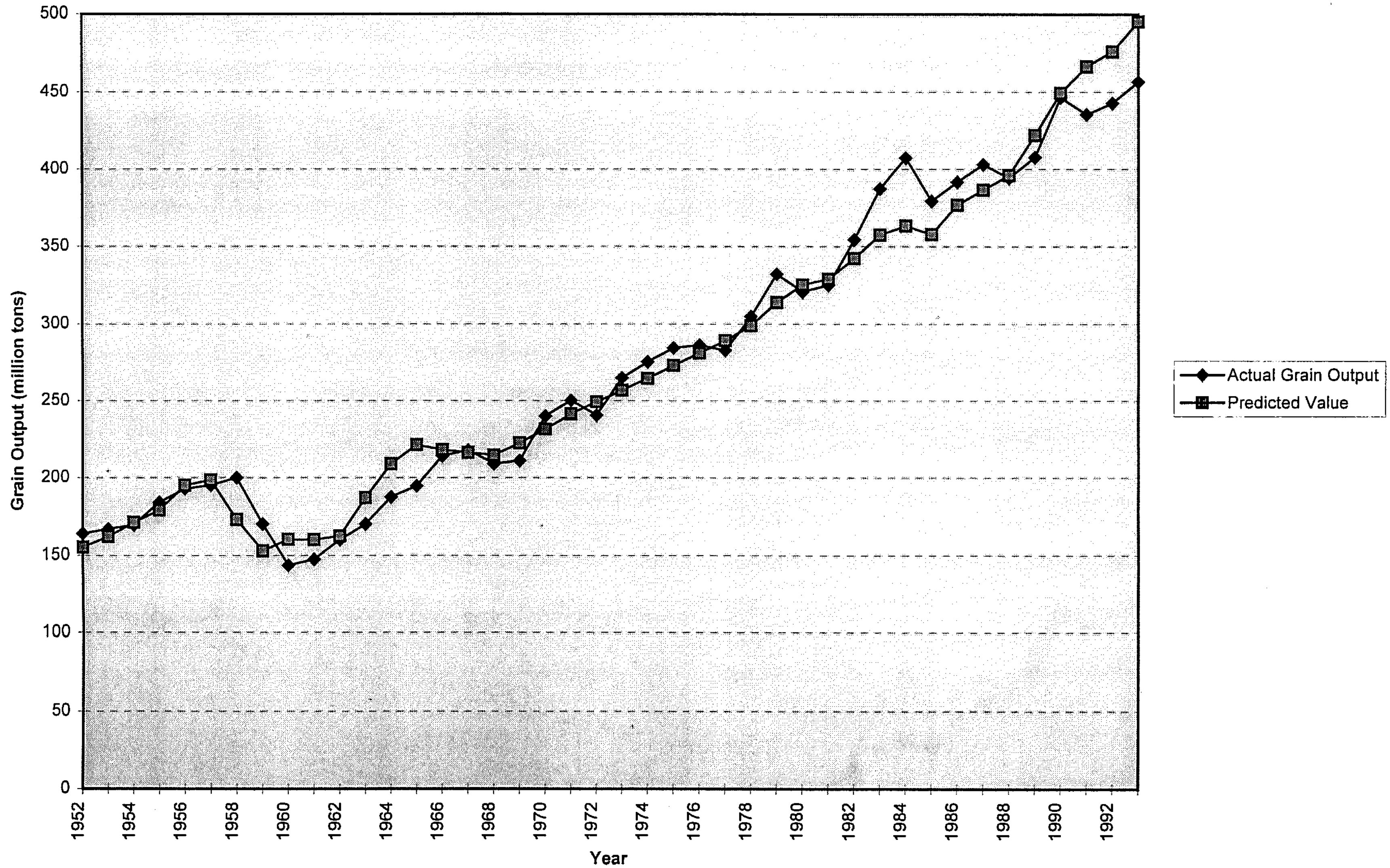


Figure 2: Simulation for Equation 4.4

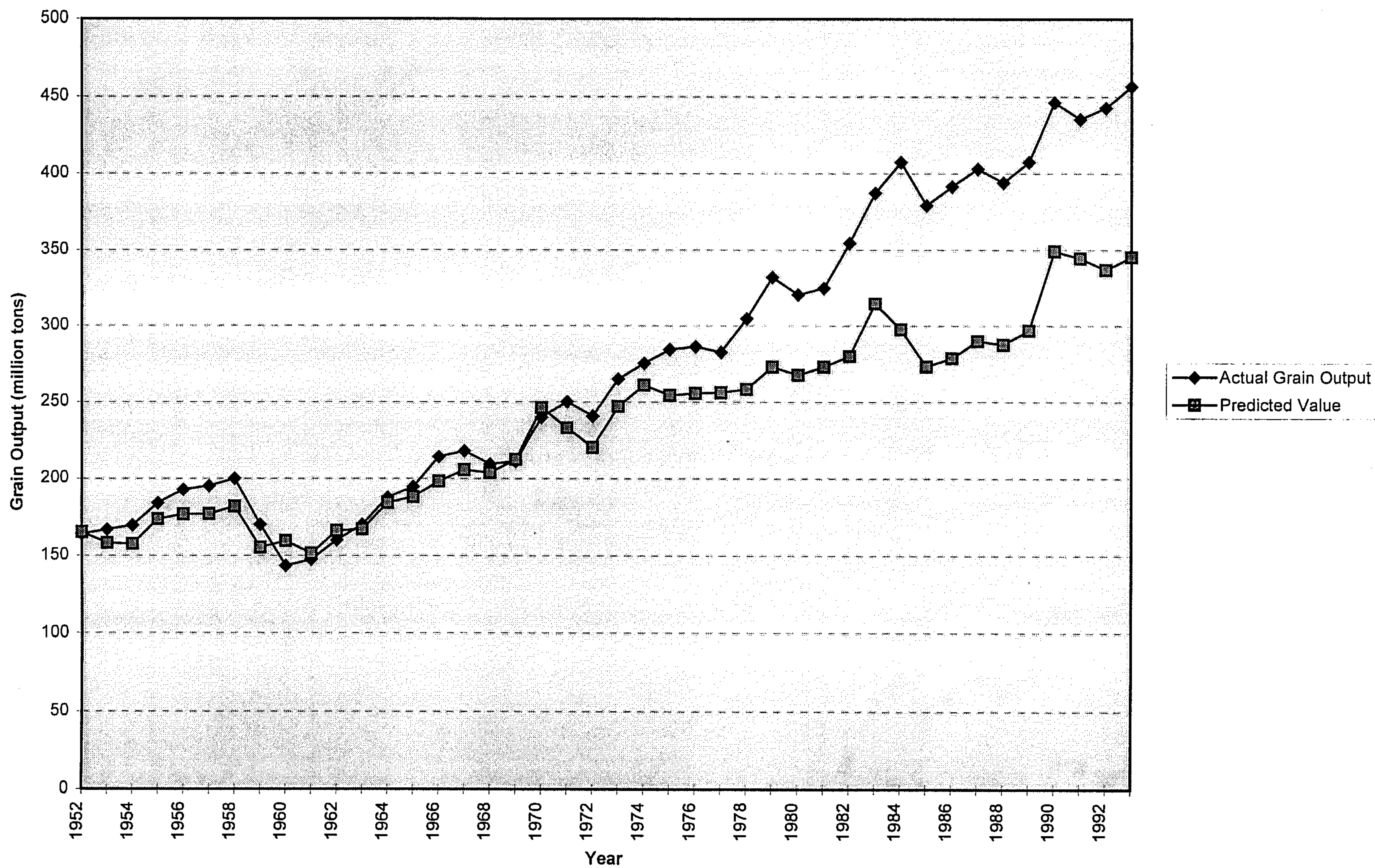


Figure 3: Simulation for VAR (LG,2)

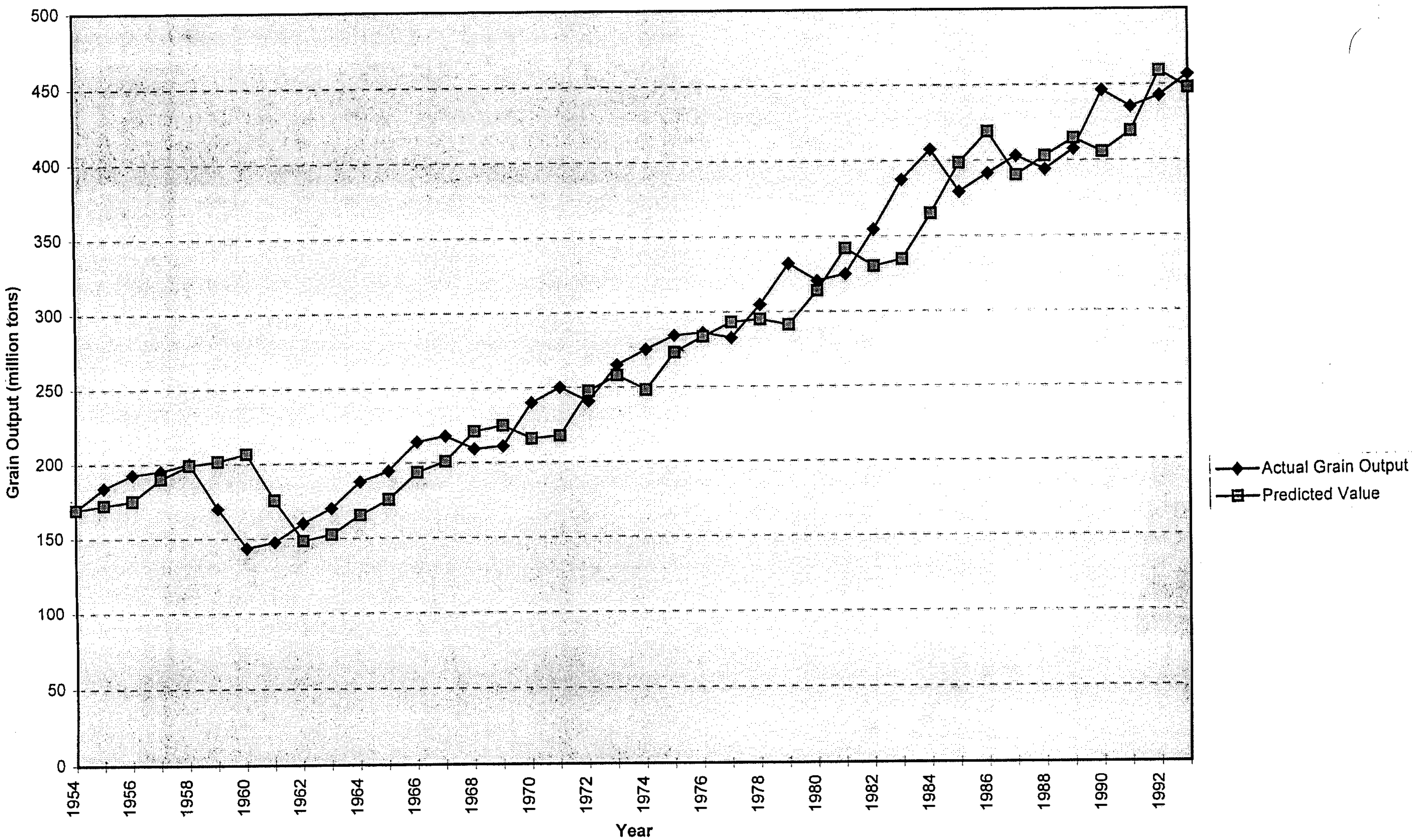
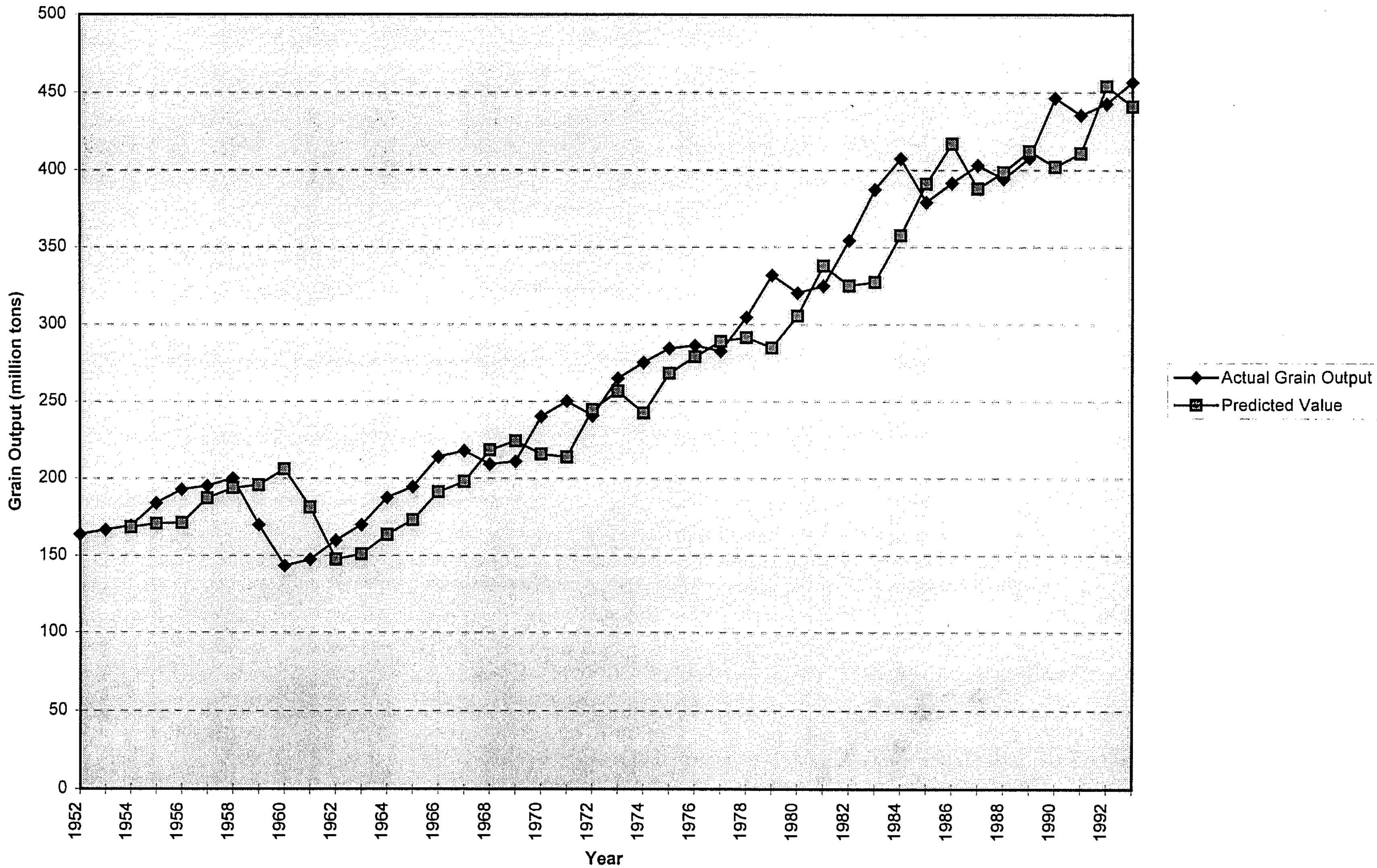


Figure 4: Simulation for VAR (LG,2;LS,2) Model



Furthermore, the following projections and scenario analysis in Table 3.5 are presented based on both the qualitative and the quantitative analysis previously conducted. The assumptions in forecasts and scenario analysis are as follows. It is assumed that during 1995-2030, the annual grain consumption per capita growth remains at 0.2% constantly, the population growth rate is chosen two scenarios to be 0.82% and 1.1%. On the grain production side, the assumptions are as follows: it is expected that the current time trend for technological improvement in the grain sector can be continued. The annual change of land inputs will maintain at -0.252%, which is derived from the arithmetic average during 1952-1993; and the rates for machinery input and chemical fertilizer are 21.9% and 16.6% respectively, based on the average during 1952-93. An assessment of the possible changes in short term factors, namely the government policy represented by grain-cotton price ratios and weather conditions, are rather difficult. The value for the grain-cotton price ratio taken in this study is 1.077615, the average of 1952-57, 1961-66, 1978-93, which in effect assumes that the favorable government policy will be stipulated and reflected in the agricultural pricing system in China in the future. The value for the weather conditions factor will be the average proportion of sown areas suffering from natural disasters during the period 1978-1993, which is 11.52 million ha, because the data prior to 1978 were often distorted for political purposes. The scenario analysis presented in Table 3-5 can be easily extended by setting low, medium and high assumptions on each element involved in related models. In view of the detailed discussions of these issues and assumptions offered by the World Bank (1985), OECD (1985, 1995), Chen and Buckwell (1991), only a brief outline is presented in Table 3.5. The scenario analysis results are based on the following models:

-Projection one: Grain production is estimated based on the results derived from Equation

3.2, which is $LnG = -1.7878 + 0.97842LnS - 0.22316\ LnM + 0.28331\ LnF + 0.0302\ T$. The grain consumption is estimated based on the constant per capita consumption growth and two different assumptions for population growth, namely low at 0.82% and high at 1.1%. The consumption side for other scenarios remains the same fashion.

-Projection two: The grain production is estimated based on the results derived from Equation 4.4, which is $LnG = -5.9238 + 1.3793\ LnS - 0.1125\ LnW + 0.2706\ Ln(Pg/Pc) + 0.0373\ T$.

-Projection three: The grain production is estimated based on the results derived from VAR(LG;2) model, $LnG_t = 0.078092 + 0.9947LnG_{t-1} + 0.00061662LnG_{t-2}$.

-Projection four: The grain production is estimated based on the results derived from VAR(LG,LS;2) model, $LnG_t = 2.0094 + 1.1069LnG_{t-1} - 0.13287LnG_{t-2} - 0.25808LnS_{t-1} + 0.11057LnS_{t-2}$.

-Projection five, six, seven and eight[26] : The grain production is estimated based on the results derived from ECM Model, which is $\Delta LnG_t = 22.367 - 2.0651\Delta LnK_t - 1.0338\Delta LnY_{t-1} - 1.5357\Delta LnL_t - 0.43033LnG_{t-1} - 5.9763\ LnK_{t-1} - 0.45632LnY_{t-1} + 2.0406Ln\ L_{t-1}$.

From Table 3.5, it seems rather difficult to draw any conclusion on the potential for China's grain self-sufficiency issue. Because the results derived from this study are based on time-series data, their projections for the short term are more reliable than those for the long term. Therefore, projections for the year 2000 are believed to be more probable. Another

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[26]Scenario five was estimated by my previous study (1996), where G is grain output, K quantity of cultivated land, Y GDP, L labor force in the primary industry. More explanation is presented in Appendix B. Other scenario are directly adopted from previous studies of other researchers or international organizations.

important result from the above analysis is that the trend for technological improvement in grain production will have a significant impact on China's future grain output. It should be noted that the projections based on Equations 3.2 and 3.4, which both assume that the current time trend for technological improvement will continue, are much higher than the figures derived from the ECM model, which has not integrated the technological factor explicitly in the model and simply assumed the technological improvement has been reflected by the increase in GDP over time.

Table 3.5 Projections and Scenario Analysis[27]

Unit: Million tonnes

Year	Scenarios based on different models/sources	Projections of grain output	Grain surplus (+)/ deficit (-) under a low consumption scenario	Grain surplus (+)/ deficit (-) under a high consumption scenario
2000	1.Eqn. 3.2	598.16	121.63	114.97
	2.Eqn. 4.4	425.67	-50.86	-57.52
	3.Var(LG,2)	494.72	18.19	11.53
	4.Var(LG,2;LS,2)	475.79	-0.74	-7.4
	5.ECM Model	370.45	-106.08	-112.74
	6.World Bank (1985b)	480.00	3.47	-3.19
	7.OECD (1995)	490-500	13.47-23.47	6.81-16.81
	8.Chen & Buckwell (1991)	500-585	23.47-108.47	16.81-101.81
2030	1.Eqn. 3.2	1345.15	698.72	632.82
	2.Eqn. 4.4	943.18	296.75	230.85
	3.Var(LG,2)	737.22	90.79	24.89
	4.Var(LG,2;LS,2)	869.67	223.24	157.34
	5.ECM Model	481.38	-165.05	-230.95

Note: 1. The figures for year 2000 under the low consumption scenario are 476.53 million tonnes and 646.43 for 2030. Under a high consumption scenario, these figures are 483.19 by 2000 and 712.33 by 2030 accordingly based on the results manipulated in this study.
2. The detailed spreadsheets of the projections are presented in Appendix Table A.a 4.

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[27]The Simulation for Scenario 1-4 in Figure 5 & 6 in Appendix A.

It is worthwhile to conduct further research on the measurement of the contribution made by technological progress to grain production in China over the next three decades. More scenarios can be presented by setting different assumptions on each factor involved or by adopting other proposed equations. The extension of the scenario analysis can also reflect the implications of various policies on the different assumptions for each factor. In this study, the results derived from Equation 4.4 based on supply response analysis, are regarded as the most probable outcome. The projection of Equation 4.4 indicates that rapid increase in grain consumption will exceed production in the near future, but in the long term, grain output will be improved with substantial technological progress and sound government policies on each key factor in grain production.

CHAPTER 4

CONCLUSIONS AND AVENUES FOR RESEARCH

The paper was initially intended to provide a comprehensive analysis of both grain consumption and production, which would then serve as the basis for forecasting the potential for self-sufficiency in grain over the next three decades in China. As the research progressed, it became apparent that the modelling of grain production functions, especially the econometric analysis and mathematical predictions, required much more work than expected.

In Chapter 2, the qualitative discussion of grain consumption and production since the founding of the People's Republic of China has identified factors like land, labor inputs, agricultural infrastructure, industrial inputs, technological improvement and the state of nature as exerting significant impacts on grain production. It was stressed that government policy and the pricing system in agriculture have played an important role in explaining the erratic development course of grain production.

In Chapter 3, it was argued that, in comparison with available techniques for modelling agricultural production, the Cobb-Douglas production function and supply response analysis are more suitable for modelling grain production in China. The empirical results derived in this paper are generally in line with those obtained by other researchers and some important issues overlooked by previous studies, such as the stationarity of data sets, have been considered. The results and projections of the proposed model were encouraging. It was realized that without an increase in land input, the use of more labor would not increase total output. Furthermore, significant production growth in China in the future will rely on the continuation in technological improvement and sound government policies. It is noted that in general, the economic performance of China has been spectacular. On the production side, the prospects are not clear but it is obvious that the loss of cropland accompanying the accelerated industrial growth will have many negative effects on the growth of grain production. On the consumption side, the huge population base together with the increase in per capita food consumption resulting from the improvement of living standard will definitely drive total food consumption up at a rapid race.

In order to deal with the limits of data and other constraints, this paper has pursued a more pragmatic approach than would be the case in literature pertaining to western countries. The emergence of the theory of the producer and the consumer, which makes great use of duality theory, has been a result of the combination of empirical econometric analysis and abstract theoretical analysis. This process is still in its infancy as far as China's Agricultural economy is concerned. This paper may be regarded as a small step toward the study of China's Agricultural economy. A computable general equilibrium model of China might be more fruitful for analyzing China's agriculture sector. Also, analyses of different regions across China and single products such as rice, wheat and soybean can be conducted with cross-sectional data. The direction of research in production estimation should pay greater attention to the role that technology and government policies play in the sustainable development of agricultural products. The policy implications should be examined more closely in future research because the principal concern of research in grain production is not only to establish reliable models, but to provide suggestions to policymakers.

APPENDIX A

STATISTICAL DATA AND SIMULATIONS

Table A.a 1 Grain Output, Grain crops Sown area and Labor input in China, 1952-93

Year	a:Grain Output (10,000 tonnes)	b:Sown Areas (1000ha)	c:Labor (10 thousand)
1952	16392	123978.7	17317
1953	16683	126636.7	17748
1954	16952	128994.7	18152
1955	18394	129839.3	18539
1956	19275	136339.3	18545
1957	19505	133633.3	19310
1958	20000	127613.3	15492
1959	17000	116022.7	16273
1960	14350	122429.3	17019
1961	14750	121443.3	19749
1962	16000	121620.7	21278
1963	17000	120741.3	21968
1964	18750	122103.3	22803
1965	19453	119627.3	23398
1966	21400	120988	24299
1967	21782	119230	25167
1968	20906	116157.3	26065
1969	21097	117604	27119
1970	23996	119267.3	27814
1971	25014	120846	28400
1972	24048	121209.3	28286
1973	26494	121156	28861
1974	27527	120976	29222
1975	28452	121062	29460
1976	28631	120743.3	29448
1977	28273	120400	29345
1978	30477	120587.3	29426
1979	33212	119262.7	29425
1980	32056	117234	30211
1981	32502	114958	31171
1982	35450	113462.7	32013
1983	38728	114047.3	32510
1984	40731	112884	32096.48
1985	37911	108845	32349.2
1986	39151	110933	32460.48
1987	40298	111268	32878.56
1988	39408	110123	33484.88
1989	40755	112205	34496.8
1990	44624	113466	35410.96
1991	43529	112314	36271.04
1992	44265.8	110560	36159.76
1993	45648.8	110509	35324.64

Notes: (1) Figures up to 1983 in Columns (a) and (b) are from TJNJ 1984,141, 137 and (c) are from TJNJ 1984,109. Figures for 1984-1993 are from TJNJ 1994, 345, 342 and 83.
(2)In Column (c), the statistical standard prior to 1978 is slightly different from those afterwards. The data after 1978 have been used to adjust with the conversion factor as 1.04.

Table A.a 2 Inputs and major factors to Grain Production in China

Year	a:Total horsepower of Agricultural machinery (10,000kw)	b:Irrigated Area (10,000 ha)	c:Consumption of Chemical Fertilizers (10,000 tonnes)
1952	18.3875	1995.9	7.8
1953	38.9815	2143.5	13.7
1954	59.5755	2291.1	19.6
1955	80.1695	2438.7	25.5
1956	100.7635	2586.3	31.4
1957	121.3575	2733.9	37.3
1958	248.4519	2798.02	42.44
1959	375.5463	2862.14	47.58
1960	502.6407	2926.26	52.72
1961	629.7351	2990.38	57.86
1962	756.8295	3054.5	63
1963	870.832	3138.167	106.7333
1964	984.8345	3221.833	150.4667
1965	1098.837	3305.5	194.2
1966	1918.127	3397.118	247.2615
1967	2737.418	3488.735	300.3231
1968	3556.708	3580.353	353.3846
1969	4375.999	3671.971	406.4462
1970	5195.289	3763.588	459.5077
1971	6014.58	3855.206	512.5692
1972	6833.87	3946.824	565.6308
1973	7653.16	4038.442	618.6923
1974	8472.451	4130.059	671.7538
1975	9291.741	4221.677	724.8154
1976	10111.03	4313.295	777.8769
1977	10930.32	4404.912	830.9385
1978	11749.9	4496.53	884
1979	13379.48	4500.3	1086.3
1980	14745.7	4488.81	1269.4
1981	15680.12	4457.4	1334.9
1982	16614.21	4417.7	1513.4
1983	18022.1	4464.41	1659.8
1984	19497.22	4445.3	1739.8
1985	20912.5	4403.59	1775.8
1986	22950	4422.58	1930.6
1987	24836	4440.3	1999.3
1988	26575	4437.59	2141.5
1989	28067	4491.72	2357.1
1990	28707.7	4740.31	2590.3
1991	29388.6	4782.21	2805.1
1992	30308.4	4859.01	2930.2
1993	31816.6	4872.79	3151.9

Notes: (1) Figures up to 1982 in Columns (a) and (b) are from TJNJ 1985, 275, 281. Figures for 1983-1993 are from TJNJ 1994, 332, 335.

Table A.a 3 Natural disaster affected areas, Chemical Fertilizer Consumption and Prices Index

Year	a:Disaster affected Areas (10,000 ha)	b:Grain Purchasing Price (1978=100)	c: Cotton Purchasing Price (1978=100)	d: Chemical Fertilizer retail price 1978=100	Pg/Pc
1952	443	52.54366	80.33363	160.1732	0.654068
1953	708	59.68109	75.94381	157.5758	0.785859
1954	1259	59.60516	77.17296	143.7229	0.772358
1955	787	59.60516	78.84109	147.619	0.756016
1956	1523	60.82005	78.84109	147.619	0.771426
1957	1498	61.50342	78.84109	138.5281	0.780093
1958	782	63.78132	78.13872	129.8701	0.816258
1959	1373	62.26272	78.13872	117.316	0.796823
1960	2498	64.54062	78.13872	116.8831	0.825975
1961	2883	80.8656	79.89464	116.8831	1.012153
1962	1667	81.24525	79.89464	116.8831	1.016905
1963	2002	87.01595	87.79631	116.8831	0.991112
1964	1264	87.01595	87.79631	103.8961	0.991112
1965	1122	87.01595	89.55224	103.8961	0.971678
1966	976	89.6735	89.55224	103.8961	1.001354
1967	719	92.33106	89.55224	98.7013	1.03103
1968	753	91.57175	89.55224	98.7013	1.022551
1969	797	91.41989	89.55224	98.7013	1.020855
1970	330	91.57175	89.55224	98.7013	1.022551
1971	745	95.74791	89.64004	96.1039	1.068138
1972	1718	97.19058	92.18613	96.1039	1.054286
1973	762	96.35535	89.55224	96.1039	1.075968
1974	653	95.67198	92.18613	97.8355	1.037813
1975	1024	96.58314	90.86918	97.8355	1.062881
976	1144	97.03872	88.49868	102.1645	1.096499
1977	1516	97.41838	91.30817	96.5368	1.066919
1978	2180	100	100	100	1
1979	1512	125.5505	125.3	99.7	1.001999
1980	2232	136.9021	145.6	99.7997	0.940261
1981	1874	144.9127	152.6	99.8995	0.949624
1982	1612	148.899	154.9	100.6987	0.961259
1983	1621	111.0858	155.2	103.1155	0.715759
1984	1526	150	156.9	115.3862	0.956023
1985	2271	157.9727	153.3	119.7709	1.030481
1986	2366	176.8793	152.5	118.9325	1.159864
1987	2039	193.0524	159.7	128.8039	1.208844
1988	2394	214.0091	173.4	152.7614	1.234193
1989	2445	284.738	212.8	179.1891	1.338055
1990	1782	271.8299	274.7	185.4607	0.989552
1991	2781	257.1374	280.5	191.3955	0.916711
1992	2590	281.805	266.5	198.4771	1.05743
1993	2313	335.305	297.1	220.5081	1.128593

Notes:(1) Figures up to 1978 in Columns a, b, c and d are from TJNJ 1984,190, 448, 450 and 446. Figures for 1978-93 are from TJNJ 1994, 359, 245 and 239.
(2) Price indices are adjusted before and after 1978 with 1978 as the base year.

Table A.a 4 Projections of grain consumption and production 1997-2030 (Unit: million tonnes)

Year	a:Consumption-1	b:Consumption-2	c:Output-1	d:Output-2	e:Output-3	f:Output-4
1997	462.2191	464.7901	551.6035	393.1165	473.3587	455.0864
1998	466.9414	470.8426	566.7071	403.6813	481.2589	466.3901
1999	471.7118	476.9739	582.2243	414.5301	486.6469	462.3304
2000	476.531	483.185	598.1664	425.6704	494.729	475.7876
2001	481.3994	489.4771	614.545	437.1101	500.2434	469.5874
2002	486.3176	495 8511	631.3721	448.8572	508.5103	485.7667
2003	491.286	502.308	648.6599	460.9201	514.1533	476.7921
2004	496.3052	508.8491	666.4211	473.3071	522.6082	496.4216
2005	501.3757	515.4753	684.6687	486.027	528.382	483.86
2006	506.4979	522.1878	703.4158	499.0888	537.0282	507.8729
2007	511.6725	528.9878	722.6763	512.5015	542.9352	490.6828
2008	516.9	535.8762	742.4642	526.2748	551.7757	520.2756
2009	522.1808	542.8544	762.7938	540.4182	557.8181	497.1221
2010	527.5156	549.9235	783.6802	554.9417	566.8562	533.83
2011	532.9049	557.0846	805.1384	569.8555	573.0364	503.0022
2012	538.3493	564.3389	827.1842	585.1701	582.2754	548.7964
2013	543.8493	571.6878	849.8336	600.8963	588.5956	508.1012
2014	549.4055	579.1323	873.1032	617.0451	598.0388	565.5154
2015	555.0184	586.6737	897.01	633.6279	604.5014	512.142
2016	560.6887	594.3134	921.5713	650.6564	614.1521	584.4362
2017	566.4169	602.0525	946.8052	668.1425	620.7595	514.7811
2018	572.2037	609.8925	972.73	686.0986	630.6209	606.156
2019	578.0495	617.8345	999.3647	704.5371	637.3757	515.5978
2020	583.9551	625.8799	1026.729	723.4713	647.4512	631.4769
2021	589.921	634.0301	1054.842	742.9142	654.3555	514.085
2022	595.9479	642.2865	1083.725	762.8797	664.6486	661.4902
2023	602.0363	650.6503	1113.399	783.3818	671.705	509.6431
2024	608.187	659.1231	1143.885	804.4348	682.219	697.7006
2025	614.4005	667.7062	1175.206	826.0536	689.43	501.5825
2026	620.6774	676.4011	1207.385	848.2535	700.1683	742.2195
2027	627.0185	685.2092	1240.445	871.0499	707.5363	489.1392
2028	633.4244	694.132	1274.41	894.459	718.5024	798.0684
2029	639.8957	703.171	1309.305	918.4972	726.03	471.5125
2030	646.4331	712.3276	1345.156	943.1814	737.2274	869.6755

Notes: (1) Figures in Column (a) are based on 0.82% population growth rate, where in Column (b) the rate is assumed to be 1.1%.

(2) Figures in Column (c) are predicted based on Equation. 3.2, Column (d) base on Equation 4.4, Column (e) on VAR(LG,2) Model and Column (f) on VAR(LG2 ;LS,2) Model.

Figure 5: Simulation for Scenario 1-4 (Table 3.5) by 2000

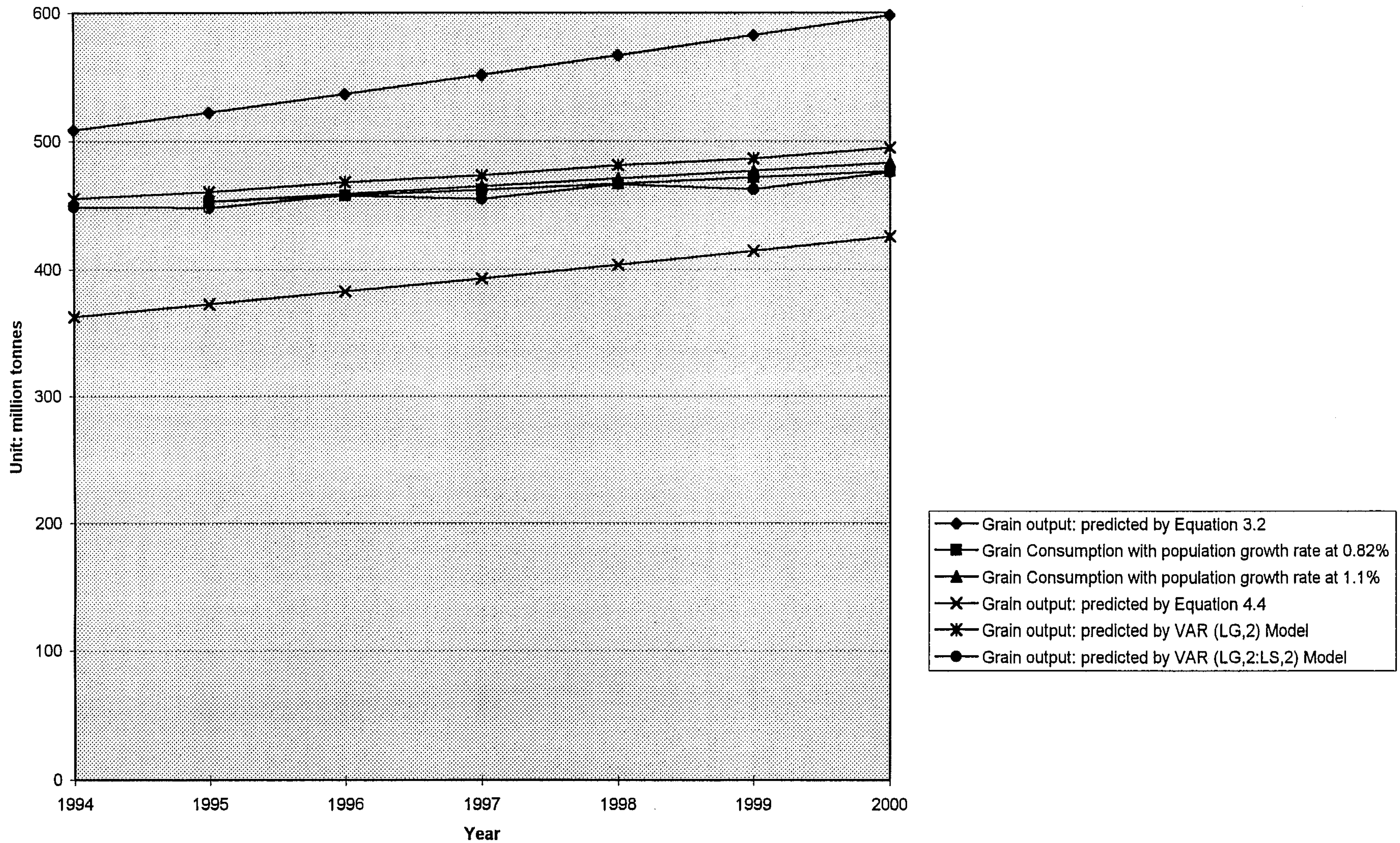
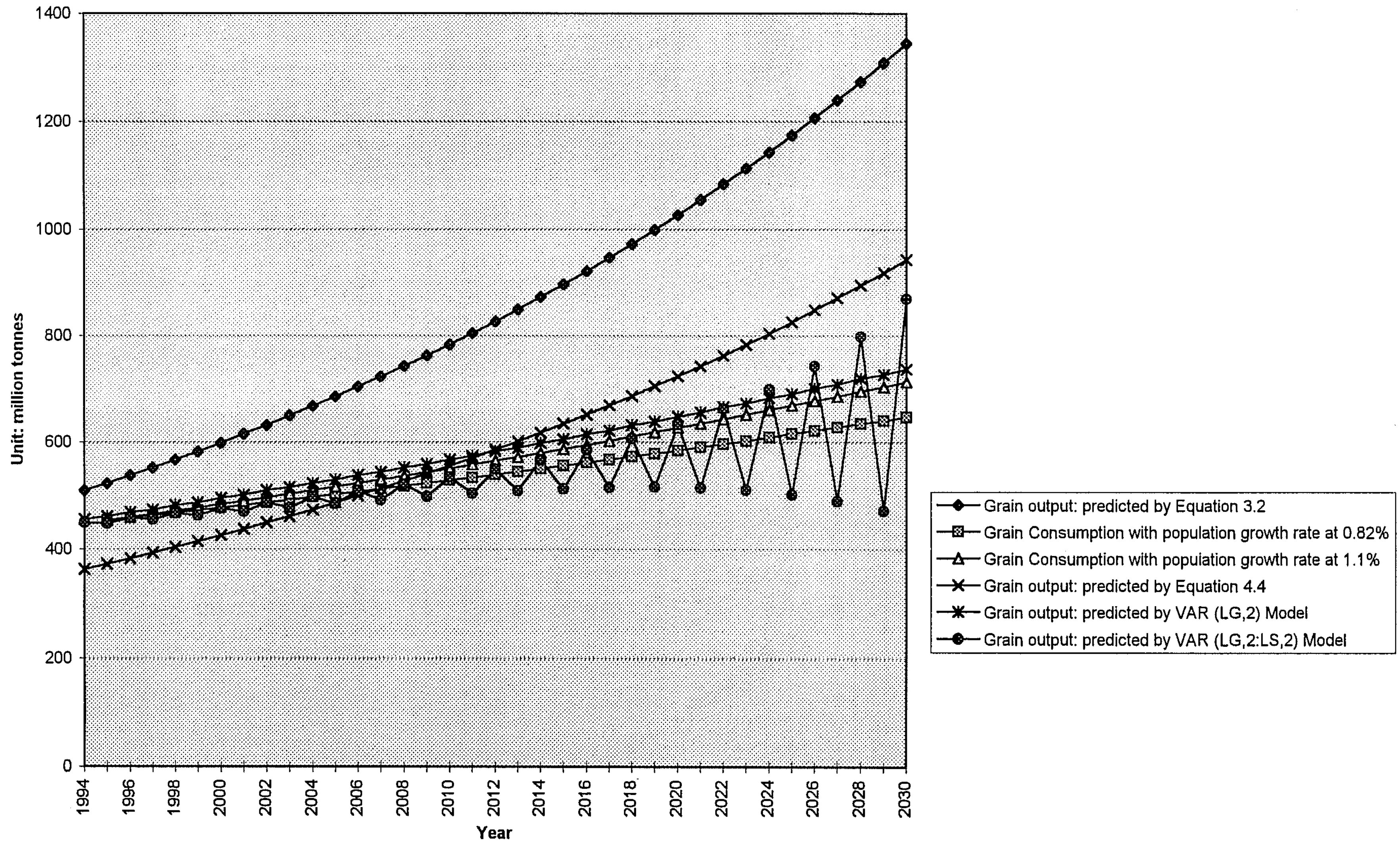


Figure 6: Simulation for Scenario 1-4 (Table 3.5) by 2030



APPENDIX B

TIME-SERIES ANALYSIS

In previous studies, whether the data are stationary or not was often overlooked. Since the above models are estimated with time-series data, it is advisable to check the stationarity of the data in order to avoid spurious regression. Even though the basic results derived from OLS (Ordinary- Least- Square regression) in this paper are generally in accordance with theoretical considerations, the relevant tests are conducted and my time-series analysis supports the hypothesis that the variables involved in the models are cointergrated. In terms of techniques, ARIMA (AutoRegressive Integrated Moving Average), Unit-Root tests, and cointegration tests should be applied to each variable to justify whether the involved variables are stationary or not, i.e., whether or not the OLS regression will have proper explanatory power, and whether or not the variables involved are cointegrated.

If the variables involved are non-stationary but cointegrated, then the error-correction model (ECM) is suitable for representing both the long run and short-run equilibrium for grain production. The ECM can be represented as follows:

(A1) $\Delta LnY_t = \beta\, \Delta X_t + \gamma\, (LnY_{t-1} - \alpha\, X_{t-1}) + u,$

where the error correction term $LnY_{t-1} - \alpha\, X_{t-1}$ reflects the long-run equilibrium for this time-series model, which is captured by the C-D production function proposed in Section 3.3. In other words, the grain output and inputs can be cointegrated and the error correction terms will be stationary in the long run; β is the vector of parameters corresponding to the first difference of the explanatory variables which captures the short-run effects on grain output; and α is the cointegrating vector. Because the ECM Model integrates both the long run and the short run effects of inputs on output mainly based on statistical rather than economic interpretation, this study chose to adopt the Supply Response Analysis approach which interprets both long run and short run effects more vigorously.

A.b.1 Test of Stationarity

To test for stationarity, a visual plot of the data is drawn as the first step in the analysis of the time series concerned. The impression from all the time series data seems to show a smooth trend over time: all go upward except the time series for total sown areas. These time series seem to be non-stationary because, at least visually, the mean, variance and autocovariances of the individual series do not seem to be invariant over time. The formal tests of stationarity will be introduced in the next sections.

A.b.2 ARIMA (Autoregressive Integrated Moving Average) Tests

The ARIMA test provides results for the Box-Jenkins approach to the analysis of Autoregressive Integrated Moving Average models of each individual time series involved. Taking into consideration the theoretical analysis and regressions results derived in the previous parts of the paper, I now present the results of stationarity tests for Equation 3.1 in Section 3.3[28].

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[28] In fact, relevant tests have also conducted for other models proposed in this paper and the results for each variable are basically equivalent to those presented for each log variable.

It has been shown[29] that autocorrelation coefficients are expected to be approximately normally distributed with zero mean and variance 1/n, where n is the sample size, i.e., for data of Equation 3.1, the confidence interval at 95% level for any autocorrelations will be (-0.3024 0.3024). These results show that the original series for involved variables are all integrated of high order, a fact which implies that either the data are poor or the test might not be relevant.

Table A.b.1 ARIMA Results for each variable in Equation 3.1

Variable	Autocorrelations[30]												
Lag:	1	2	3	4	5	6	7	8	9	10	11	12	
LnG	0.93	0.86	0.79	0.73	0.67	0.63	0.56	0.48	0.40	0.30	0.21	0.14	(10)
LnS	0.86	0.71	0.58	0.48	0.36	0.29	0.26	0.20	0.13	0.07	0.01	-0.04	(6)
LnM	0.91	0.83	0.75	0.67	0.58	0.51	0.44	0.38	0.32	0.25	0.19	0.13	(10)
Ln F	0.92	0.85	0.77	0.70	0.63	0.56	0.48	0.41	0.33	0.25	0.18	0.12	(10)
LnI	0.90	0.81	0.72	0.65	0.59	0.52	0.46	0.40	0.34	0.27	0.21	0.15	(10)
LnL	0.93	0.86	0.77	0.70	0.64	0.54	0.44	0.35	0.27	0.21	0.14	0.08	(9)

A.b 3 Unit Root Tests

Besides the ARIMA test, Dickey-Fuller Unit Root test is considered to be a more formal means of testing for stationarity, although at the same time more controversial in the sense of how to interpret the results under different hypotheses. The relevant results are shown in Table A.b.2.

The results are in accordance, although not identical, with those derived from the ARIMA

[29]By Bartlett M.S. (1946): " On the Theoretical Specification of Sampling Properties of Autocorrelated Time Series," *Journal of the Royal Statistical Society*, Series B, Vol. 27, 27-41.

[30] The sample autocorrelations (r_j) are derived by first calculating the sample autocovariances as $c_j = 1/N \Sigma^n_{t=j+1} ((z_t - z)(z_{t-j} - z))$, j=0,1,2, ... and then $r_j = c_j / c_0$, j=1,2,..., where n is sample size and z is the sample mean.

test, which indicate that we may reject the unit root hypothesis at the 90% confidence level at first difference order (only first difference test results are presented in Table A.b.2) for most variables except for labor input variable. Although it should be always cautious before drawing any conclusion based on most stationarity tests, it is safe to believe that all the original time series for involved variables are all non-stationary and integrated of high order based on both the ARIMA and Unit-Root tests. The results of cointegration tests are proved to be in line with this argument. The estimation with I(1) adjustment has been conducted but the results (not presented in this paper) are not satisfactory possibly because of the poor quality of the data.

Table A.b.2 T-test statistics for Unit Root Tests

Difference	Variable: LG	LS	LM	LF	LI	LL
0	-2.4110	-3.1832	-1.3872	-1.0149	-1.8188	-1.4634
1	-3.4908	-4.4336	-5.6524	-4.7786	-3.4210	-2.7794

Note: Only t-test statistics for different order of difference with constant and trends were shown above and the asymptotic critical value at 90% confidence level is -3.13.

A.b.4 Cointegration Tests

The cointegration tests for Equation 3.2 are presented in Table A.b.3.. Fortunately, both the t-test and the z-test statistics for the cointegrating regression with or without trend show that the null hypothesis of non-stationarity can be rejected. However, since the order of difference for each variable to achieve stationarity is not the same, this test results should be used with caution. Technically speaking, the "trends" in the involved variables can cancel each other out. The reported high R^2 value and low Dubin-Watson value also suggest the possibility of cointegration.

The test results for other proposed production functions and supply response functions are in line with those presented in this section. Therefore, both the results derived from the single aggregate production function and the supply response analysis in Section 3.3 and Section 3.4 are reliable, although further refinements are still required.

Table A.b.3 Results for Cointegration Tests for Equation 3.2

	T-test statistics	R^2	Dubin-Watson Statistics
Constant, no Trend	-4.7812 (-3.81)	0.9355	0.6689
with Constant & Trend	-4.8949 (-4.15)	0.9701	1.006

Note: Asymptotic critical value at the 90% confidence level is in parentheses.

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