复旦管理学杰出贡献奖获奖者代表成果集

2006

中国管理研究与实践

ZHONGGUO GUANLI YANJIU YU SHIJIAN

陈锡康 朱道立 陈剑 著

复旦大学出版社

图书在版编目(CIP)数据

中国管理研究与实践:复旦管理学杰出贡献奖获奖者代表成果集.2006/陈锡康,朱道立,陈剑著.—上海:复旦大学出版社,2010.11
ISBN 978-7-309-07600-4

Ⅰ.①中… Ⅱ.①陈… ②朱… ③陈… Ⅲ.①管理学-中国-文集 Ⅳ.①C93-53

中国版本图书馆CIP数据核字(2010)第183351号

中国管理研究与实践——复旦管理学杰出贡献奖获奖者代表成果集(2006)
陈锡康 朱道立 陈 剑 著

出版发行 复旦大学出版社 上海市国权路579号 邮编200433
86-21-65642857(门市零售)
86-21-65118853(团体订购) 86-21-65109143(外埠邮购)
fupnet@fudanpress.com http://www.fudanpress.com

责任编辑 徐惠平 岑品杰
出 品 人 贺圣遂

印　　刷 同济大学印刷厂
开　　本 787×1092 1/16
印　　张 39.19
字　　数 858千
版　　次 2010年11月第1版第1次印刷
印　　数 1—2 500

书　　号 ISBN 978-7-309-07600-4/C·164
定　　价 60.00元

序 言 一

李岚清

最近 20 多年来，管理学在我国日益受到人们的重视，这和我国的改革开放、经济社会快速发展有关，也和我国步入社会主义市场经济有关。其实，新中国建立以来，在经济和社会领域内都存在大量的涉及管理学的问题。我长期在大型企业、对外经济贸易部门和从事经济方面的领导工作中也都深切感受到这一点。但是由于种种原因，管理学在相当长的时期内未能得到应有的重视。

管理学真正成为一门独立的科学，走进中国人的专业视野，全面进入中国的科学研究和高等教育体系，也就是最近 20 多年的事情。改革开放以来，中国的经济发展突飞猛进，科学技术日新月异，经济发展和社会进步越来越离不开管理科学的支撑。社会管理、环境管理、公共管理、企业管理等等各个方面都对管理学提出了新的要求。经济社会领域改革的不断深入，在参与国际竞争中要取得持续的优势，这些都迫切需要进一步加强管理科学的研究，提高管理水平。可以说，需要管理学解决的问题越来越多，管理渗透到社会、经济生活的各个方面。当前中国管理科学正迸发出空前的生机和活力，同时也面临着空前的机遇和挑战。

管理学是一门应用性、实践性很强的学科，作为一门科学，它的一些理论和方法在世界范围内具有共性。但是管理要获得成功则必须植根于一个国家的社会组织和民族文化之中。要真正解决好中国的管理问题，要让中国人对世界范围内涉及自己的管理问题有话语权和平等的参与权，最终还是要依靠中国人自己。管理科学是一个国家软实力的重要组成部分，我们要不断地构建有中国特色的管理科学理论，要具备并不断提高解决各类实际管理问题的能力，要培养出大批有很高学养和丰富经验的管理者，要花大力气建设高质量的管理教育体系，最关键的是要有一支高水平的管理学队伍。

复旦管理学奖励基金会的宗旨在于奖励在中国管理学领域作出贡献的学者和实践工作者，推动管理学的理论和实践的结合，形成中国特色的管理科学体系，最终推动中国管理学的长远发展，促进中国管理学人才的成长，提高中国管理学的国际学术影响力。

复旦管理学杰出贡献奖到今天已经是第 5 个年头了，12 位在管理科学、工商管理和公共管理等领域有杰出贡献的学者获得了这一奖项。这次，基金会把历届获奖人的代表性成果收录成册、公开发行，一方面是希望促进管理学研究成果在全社会的共享；另一方面也希望能够激励更多的中国管理学工作者潜心研究、勇于实践，产生高水准的学术成果，推动中国的管理创新和发展。

衷心祝愿中国管理学的明天更加美好！

序 言 二

成思危

管理学是一门应用性、实践性很强的学科，既有科学的规律可循，又有艺术的运用之妙。改革开放以来，我国管理学扎根于中国特色社会主义的实践沃土，积极回答了改革开放对理论和实践提出的新课题，适应了我国经济建设的迫切需要，并在多学科相互融合中不断发展，初步形成了比较适合我国国情的管理学科体系。

从管理科学与工程方面来看，我国的总体研究水平取得了显著提高。在分析预测方法、不确定性决策理论、群体决策理论、供应链管理、管理复杂性研究等领域，还产生了一批在国际上有影响力的优秀成果。从工商管理方面来看，改革开放实践为中国特色工商管理模式的形成提供了成长沃土，我国学者在股份制公司的组织与运作、公司治理制度的建立与评价、企业战略制定与实施、企业信息管理与电子商务、非公有制企业管理等众多领域进行了深入探索，在建立符合国情的现代企业制度、提高企业管理水平方面作出了重要贡献。在发挥市场资源配置方面的基础性作用的同时，也需要政府通过适当有效的宏观管理加以引导和调控，解决发展中产生的矛盾，维护有序的市场秩序，促进社会公平，保护生态环境，改善社会保障，实现可持续发展的和谐社会，公共管理研究为国家宏观政策制定提供了重要的理论支持。

为了推动我国管理学长远发展，促进我国管理学人才的成长，提高我国管理学在国际上的学术地位和影响力，复旦管理学奖励基金会自 2006 年起，开始奖励我国在管理学学术领域作出杰出贡献的工作者，倡导管理学理论符合中国国情，并密切与实践相结合。获奖人都是活跃在当今管理学学术领域的最优秀学者，获奖人的产生经过了学界的广泛推选，经过了严格的评议过程，始终坚持“创新性、学术性和实用性”的基本评判标准，具有较高的程序公正性和实质公正性。复旦管理学杰出贡献奖是完全由学术界独立完成推选的学术奖项，现在复旦管理学杰出贡献奖逐渐被更多的人了解，产生了一定知名度，在管理学界具有了越来越大的影响力，评选出的获奖人和他们的成果代表着目前我国管理学研究的先进水平。今后我们将持续帮助获奖人出版他们的研究成果，促进学术交流，推动理论繁荣。

“创立中国特色的管理理论、建立中国自己的管理学派”不是一朝一夕可以完成的任务。复旦管理学奖励基金会将通过对中国管理学界的长期支持，努力促成这项事业的成功。现在基金会还只是做了一点基础性的工作。我相信通过 10 年、20 年的努力，通过一代又一代管理学者的辛勤工作，通过有选择地学习和吸收国外经验，有批判地继承中国传统的管理哲学和管理思想，一定能够达到这个目标。

目　　录

一、陈锡康代表学术成果汇集篇

二、朱道立代表学术成果汇集篇

三、陈剑代表学术成果汇集篇

一、陈锡康代表学术成果汇集篇

陈锡康
2006年度复旦管理学杰出贡献奖并列一等奖

陈锡康，男，1936年出生，浙江省镇海人。1957年毕业于中国人民大学，1967年于苏联列宁格勒大学研究生毕业。国际投入产出协会创建人之一及理事。现任中国科学院数学与系统科学研究院研究员、中国投入产出学会名誉理事长。

陈锡康研究员在管理科学与工程领域出版著作24部，发表论文156篇。其主要科研成果是提出和建立了投入占用产出技术，在此领域提出了一系列新的模型和计算方法，并成功地应用于全国粮食产量预测、对外贸易、农业、水利、人力资本、金融等领域。国际上一些知名科学家，如美国科学院院士W. Isard、诺贝尔经济学奖获得者W. Leontief、澳大利亚昆士兰大学教授R. C. Jensen和A. G. Kenwood等都曾给予很高评价，认为是“非常有价值的发现”、“先驱性研究”，并指出“投入占用产出及完全消耗系数的计算方法是我们领域的一项非常重要的发明和创新”。

陈锡康研究员利用投入占用产出技术和考虑报酬递减的非线性预测方程等进行全国粮食产量预测获得显著成绩，并提出了新的农作物产量预测方法——系统综合因素预测法。自1980年起，每年4月底向中央预报当年全国粮食产量，连续26年预报丰、平、歉方向正确，预测提前期为半年以上，平均误差为1.9%，为相关部门制定农业和粮食政策提供了科学依据，曾获得中央八个部门很高评价和中央主要领导人二十多次肯定和好评，认为“此项目为国家准确判断农业生产形势，进行宏观决策，安排粮食生产、储备、进口提供了科学的参考依据”，“这对我们农业生产和农村经济发展的工作指导和政策制定是很有益处的”；并曾获得国外专家好评，认为“此项预测研究比国际同类预测精确度更高”。

Yearly Grain Output Predictions in China 1980 – 2004[①]

Xikang Chen, Ju-e Guo, Cuihong Yang[②]

Abstract: China has a population of 1.3 billion and grain accordingly plays a crucial role in the Chinese economy. In this paper we suggest predicting grain output mainly by factor inputs and asset holding, and present a Systematic Integrated Prediction Approach (SIPA). The key elements of SIPA are an extended input-output model with assets, nonlinear variable coefficient forecasting equations, and using the minimum sum of the absolute values. Since 1980 we have used the approach to predict the yearly national grain output of China. The prediction lead time is more than half a year. The bumper, average, and poor harvests are accurately predicted every year. The average error rate over the period 1980 – 2004 is 1.9%.

Key Words: grain output prediction; Systematic Integrated Prediction Approach (SIPA); extended input-output model with assets; nonlinear forecasting

1 Introduction

China has a population of 1.3 billion and grain therefore has a crucially important status in the Chinese economy. At the end of 1970s, the Chinese government requested the Chinese Academy of Sciences to forecast national grain output. They set forth two preliminary demands. First, the lead time of prediction should be half a year prior to the harvest season so as to arrange grain consumption, storage, import and export as early as possible. Second, a high accuracy of prediction, in the sense that the error rate should be lower than 3%.

Worldwide, three main approaches to predicting cereal output may be distinguished. First, the meteorological approach uses statistical methods to predict cereal yield. In its forecasting equations, the main variables are temperature, sunshine, precipitation, and so

---

① *Economic Systems Research*, 2008, Vol. 20, No. 2, pp. 139 – 150.

② Xikang Chen and Cuihong Yang, Academy of Mathematics and Systems Science, Chinese Academy of Sciences, Beijing, People's Republic of China; Ju-e Guo, Management School of Xi'an Jiaotong University, Xi'an, People's Republic of China.

on. The theoretical assumption of the approach is that the fluctuation of grain output is mainly caused by meteorological factors. For example, Thompson (1969) issued a forecasting model for winter wheat yield in Kansas, USA, in which meteorological factors are the precipitation and the temperature in April, May, June and July.

Second, the statistical dynamic simulation approach studies the relationships between grain yield and effects of environmental factors such as temperature, sunshine and the concentration of CO_2 on crop photosynthesis, transpiration, respiration, solid material and seed formation. For example Wang (1995) and Wang et al. (1997) studied the effects of CO_2 density on grain yield, finding that doubling the CO_2 density increases the yield of Chinese winter wheat, corn, soybean and cotton by 28.3%, 22.9%, 67.1% and 27.0%, respectively. In addition this approach uses meteorological factors. Note, however, that it is almost impossible to obtain meteorological data for a large area over time. Therefore, this approach is difficult to use in practice and is still in its experimental stage. The third approach uses remote sensing. Because different crops are characterized by a different spectrum, it is possible to forecast cereal output using the reflected and radiant electrical and magnetic waves of ground objectives gathered by satellite sensors.

These three approaches normally have a 5 - 10% error rate compared with reported output and a two-month prediction lead time. For example, Williams et al. (1975) adopted the meteorological approach for predicting Canadian prairie crop district cereal yields at the end of June, two months prior to harvest, with an error rate of 8.8%, 4.7%, and 5.4% for wheat, oats, and barley, respectively. Hayes and Decker (1996) used the Vegetation Condition Index derived from NOAA/AVHRR (National Oceanographic and Atmospheric Administration/Advanced Very High Resolution Radiometer) satellite data since 1982 to estimate maize production in the corn belt of the USA. The forecasting results from 1985 to 1992 had a lead time of about two months and a 4.9% average error rate over the eight years. The error rate was lower than 5% for four years, between 5% and 10% for three years, and higher than 10% for one year. Since 1989, the Institute of Applied Remote Sensing of the Joint Research Center of the European Union has issued the Pilot Project for the Application of Remote Sensing to Agricultural Statistics. Quarmby et al. (1992, 1993) estimated crop areas in North Greece and arrived at an accuracy rate of 90%, when predictions were compared with realizations from official output reports. It is evident from these results that the three approaches above would not meet the two requirements of the Chinese government (i.e. a six-month prediction lead time and an error rate smaller than 3%).

2 The Systematic Integrated Prediction Approach

The approaches above predict grain output mainly from meteorological factors. Up to the present, it has been extremely difficult to predict the weather — temperature, sunshine, rainfall, and so on — two to three months ahead. In the late 1970s, we suggested predicting grain output mainly from factor inputs and asset holdings, and presented a systematic integrated prediction approach. This approach combined an extended input-output model with assets (see Chen, 1990; Chen et al., 2005), nonlinear variable coefficient forecasting equations, and the minimum sum of absolute value technique as its key methods (Chen et al., 2001).

Our theoretical assumptions were as follows. Agricultural production typically is a complex system with a multi-level structure. There are complex interrelations among its subsystems and between the system and the external environment. The characteristics of the system are nonlinear, stochastic, and dynamic.

Grain output is affected by different types of factors: (1) social, economic and production technology factors, such as agricultural policies, education level of peasants, prices, fertilizers, improved seed varieties, irrigation, machinery; (2) natural factors, such as meteorological and non-meteorological factors; and (3) other factors. Only when we consider all these factors we can effectively increase the prediction accuracy of grain output.

The first set of factors (i.e. social, economic and production technology factors) plays a critical role in increasing grain output. For example, the grain output of China in 1952 was 163.9 million tons; in 1998 it was 512.3 million tons, which is 312% when compared with the 1952 output. Over these 46 years, the changes in China's meteorological circumstances were much less spectacular. Therefore, the increase in grain output is more likely to have been caused mainly by changes in social, economic, and production technology factors. These factors not only determine the long-term trend of grain production but are also a major cause of yearly fluctuations in grain production. There have been two abrupt changes in grain output since 1949: a drastic decline from 1959 to 1961, and a sharp increase from 1981 to 1984, both of which were mainly caused by social, political, and economic factors. The systematic integrated prediction approach that we proposed is based on a synthetic method and multi-equation forecasting model.

2.1 Using the Extended Input-Output Model with Assets in Yearly Grain Output Prediction

2.1.1 Constructing the Input-Output Model with Assets for Chinese Agriculture

Under the support of the former Rural Development Research Center of the State Council of China, the Chinese Academy of Sciences and the National Natural Science Foundation of China, the Institute of Systems Science constructed an extended input-output table with assets for agriculture for 1982 (Chen et al., 1991), 1984, 1987 (Chen et al., 1992), 1992, and 1997. To predict the output of grain, cotton, and oil-bearing crops in other years, some updating calculations were done on the basis of the existing extended input-output tables.

The 1997 extended input-output table with assets for agriculture was constructed on the basis of the 1997 national input-output table, published by the National Bureau of Statistics of China (NBS). Next to augmenting the table with assets, the agriculture industry was split. For the purpose of grain output predictions, the agriculture industry in our extended input-output table with assets was divided into the following 12 sectors: rice; wheat; corn; other grain; oil-bearing crops; cotton; vegetables; other farm crops; forestry; livestock and livestock products; fishery; and other agriculture. In China, the term "grain" is the sum of rice, wheat, corn and other grain. Some sectors, including grain, cotton, and oil-bearing crops, and some important agricultural inputs, such as fertilizer and electricity, are measured not only in value units, but also in physical units. There are eight items in the asset part: sown area, cultivated land, irrigated area, labor, agricultural fixed assets, total power of agricultural machinery, large and medium tractors, and mini-tractors. The assets part for agriculture in the 1997 extended input-output table with assets is shown in Table 1.

Land and water play a very important role in grain production. For some reasons, the figures as published by NBS for cultivated land before 1996, were underestimates and cannot be used in our calculation. To date, we only have reliable figures on cultivated land for 1996 and 2001, published by NBS on the basis of the remote sensing approach. In our grain output prediction, the sown area of crops is a very important indicator. Grain output is a function of the sown area of grain and grain yield. Therefore, if we had not taken into consideration this asset, our predictions would necessarily been way off the mark. The main cause of the sudden decline in grain output from 1999 to 2003 is the sharp drop in the sown area of grain (see Table 2).

In Table 2, we see that from 1998 to 2003 grain output in China dropped very quickly, by 15.9%, from 512.3 million tons to 430.7 million tons. The sown areas of grain fell by 12.8% in the same period, from 113.79 million hectares to 99.41 million hectares, while grain yield only decreased by 3.8%. Thus, the sharp drop in Chinese grain output from 1998 to 2003 was caused mainly by the decline in sown area.

2.1.2 Using the Extended Input-Output Model with Assets for Predictions

Using the data in the asset part of our extended input-output table, we can calculate many important indicators. Examples are: consumption of chemical fertilizer and electricity per *mu* (1 hectare is equal to 15 *mu*) of sown area; fixed assets per *mu* of sown area; the ratio of irrigated to cultivated area; labor per *mu*; total power of agricultural machinery per *mu*; tractors per *mu*; the ratio of areas hit by natural disasters to total sown areas; and the ratio of total areas affected by natural disasters (which include flood, drought, wind, hail and frost, etc.) to total areas hit by natural disasters①. These indicators are very

① In areas affected by natural disasters, the actual output of crops reduces by more than 10% due to the disaster, when compared with a normal year. Areas hit by natural disasters are a subset of the areas affected by natural disasters and their actual crops' output reduces by more than 30% when compared with a normal year.

Table 1 Asset holding part for agriculture in the 1997 extended IO table of China

Items	Crop cultivation														
	Grain crops					Oil-bearing crops	Cotton	Vegetables	Other farm crops	Sub-total	Forestry	Livestock and livestock products	Fishery	Other agriculture	Total
	Rice	Wheat	Corn	Other grain	Subtotal										
Total sown area (1 000 ha)	31 765	30 057	23 775	27 315	112 912	12 381	4 491	11 288	12 897	153 969					153 969
Area of cultivated land (1 000 ha)	23 059	25 385	21 080	24 345	93 869	11 805	3 638	7 870	12 376	129 558					129 558
Irrigated area (1 000 ha)	15 257	10 020	5 706	4 019	35 002	2 830	3 235	7 435	2 737	51 239					51 239
Labor force (million persons)	40.1	26.0	26.8	15.2	108.1	14.0	12.4	49.9	11.0	195.2	14.4	93.2	31.2	14.4	348.4
Total agricultural fixed assets (billion RMB)	92.8	77.2	49.2	9.5	228.7	18.5	12.6	90.5	28.2	378.5	29.0	191.4	94.9	28.8	722.6
Total power of agricultural machinery (million kW)	49.5	79.6	41.8	13.4	184.4	6.1	5.9	5.5	3.9	205.9	36.7	92.1	52.3	33.2	420.2
Large and medium tractors (1 000 units)	22.7	255.6	219.1	71.4	568.7	18.9	18.3	16.9	12.1	635.0	30.1	14.5	1.5	8.0	689.1
Mini-tractors (1 000 units)	2 323	3 737	1 964	631	8 654	288	279	256	185	9 663	457	221	23	2 122	10 485

Sources：National Bureau of Statistics (1998，1999a，1999b)；National Development and Planning Commission et al. (1998).

Note：The latter source contains many important figures per mu of sown area by major crops，for example，data on fixed assets depreciation cost，labor，cost of plows，cost of irrigation，taxes，benefits and others. These data are collected from surveys of 60 000 rural households in 1300 counties in China.

Table 2　Total sown area of farm crops, grain output, and grain yields in China, 1998 – 2003

Year	Total sown area in farm crops (1 000 ha)	of which									Grain Output (million tons)	Grain yields (kg/ha)
			of which									
		Grain crops	Rice	Wheat	Corn	Other grain crops	Oil-bearing crops	Cotton	Vegetables	Other farm crops		
1998	155 706	113 787	31 214	29 774	25 239	27 560	12 919	4 459	12 293	12 248	512. 295	4 502. 2
1999	156 373	113 161	31 284	28 855	25 904	27 118	13 906	3 726	13 347	12 233	508. 386	4 492. 6
2000	156 300	108 463	29 962	26 653	23 056	28 792	15 400	4 041	15 237	13 159	462. 175	4 261. 2
2001	155 708	106 080	28 812	24 664	24 282	28 322	14 631	4 810	16 402	13 785	452. 637	4 266. 9
2002	154 636	103 891	28 202	23 908	24 634	27 147	14 766	4 184	17 353	14 442	457. 058	4 399. 4
2003	152 415	99 410	26 508	21 997	24 068	26 837	14 990	5 111	17 954	14 950	430. 670	4 332. 3

Sources: Rural Social and Economic Survey Team of National Statistical Bureau of China (1999, 2000, 2001, 2002, 2003). The 2003 figures are from the Ministry of Agriculture of China.

important variables in the nonlinear forecasting equations.

In particular, we use the extended input-output table with assets to calculate the total income per *mu* of sown area for grain and other important farm crops (see Table 3), net income per workday, and the profit rate of capital. Since 1981, China's grain output variation has had a close relationship with the variation of net income for grain. Net income of each crop equals the difference between the gross output value and the sum of all costs, which include all intermediate inputs, depreciation of fixed assets, taxes, and other costs of the crop. Because the net income status of grain directly influences the quantities of factor inputs and asset holding in grain production, the net income of the previous year has a significant linear correlation with the grain output of the current year.

Table 3 Net income (in RMB) per *mu* of sown area for grain crops, oil-bearing crops, and cotton, 1998 – 2003

	Grain			Oil-bearing crops		
	Rice	Wheat	Corn	Peanuts	Rapeseed	Cotton
1998	347.77	122.51	245.41	328.72	117.39	581.22
1999	260.50	110.64	157.62	274.66	95.84	292.65
2000	228.62	68.85	140.29	268.54	87.10	547.18
2001	263.75	95.46	216.08	244.66	103.08	402.97
2002	264.49	93.40	204.38	341.93	103.76	609.69
2003	301.77	117.25	235.67	358.20	172.50	844.06
2004 (projection)	369.57	192.35	271.07	371.70	232.20	597.06

Sources: Department of Price, National Development and Reform Commission (2002, 2003, & 2004); National Development and Planning Commission et al. (1998, 1999, 2000, 2001). The 2004 figures are estimated by authors on the basis of surveys in 13 provinces.

According to our calculation and forecasting, the net income of grain in 2004 will rise quickly and once again to a higher level than 1998. At the end of April, 2004, we predicted — using the systematic integrated prediction approach — and reported to the government that China would have a nice harvest in 2004. The grain output forecast for 2004 was 462 million tons, an increase of 7.3% with respect to 2003 (when the grain output was 430.7 million tons). According to the NBS (National Bureau of Statistics, 2005), the realized grain output in 2004 was 469.5 million tons, so our forecasting error rate in 2004 was 1.6%.

Using the extended input-output model with assets, we can precisely calculate the total consumption coefficients of electricity, oil, and chemical fertilizer by grain crops. It should be stressed that our results are higher than the results calculated in the traditional framework. For example, the direct input of electricity for wheat was 68.1 kilowatts per ton of wheat production. The direct consumption coefficients for electricity are given by the "electricity row" of the input coefficients matrix **A**. That is, $\mathbf{e}'_{direct} = \boldsymbol{\delta}'_{electr}\mathbf{A}$, where

$\boldsymbol{\delta}'_{electr}$ is a unit row vector with a 1 for the electricity sector and zeros elsewhere. The total electricity consumption coefficients measure the input of electricity that is used directly and indirectly per unit of final demand (of wheat, for example). They are given by

$$\mathbf{e}'_{total} = \boldsymbol{\delta}'_{electr}[(\mathbf{I}-\mathbf{A})^{-1}-\mathbf{I}] = \boldsymbol{\delta}'_{electr}\mathbf{A}(\mathbf{I}-\mathbf{A})^{-1} = \mathbf{e}'_{direct}(\mathbf{I}-\mathbf{A})^{-1}$$

For example, the total consumption of electricity for wheat was 235.4 kilowatts per ton. Chen et al. (2005) provides a detailed discussion of the input-output model that is extended with assets. Using their formula $\tilde{\mathbf{e}}'_{total} = \mathbf{e}'_{direct}(\mathbf{I}-\mathbf{A}-\hat{\boldsymbol{\alpha}}\mathbf{D})^{-1}$ yields 268.6 kilowatts per ton for the total consumption of electricity for wheat of. Here, $\hat{\boldsymbol{\alpha}}$ is the diagonal matrix with depreciation rates of fixed assets and $\mathbf{D}$ is the matrix of direct holding coefficients of fixed assets. Similar vectors of consumption coefficients are calculated for other inputs.

2.2 A Nonlinear Forecasting Equation with Diminishing Returns

In fact, functional relationships between input and output, and between assets and output, are usually nonlinear. For example, the effect of fertilizer on grain yield follows the law of diminishing returns. Fig. 1 shows that marginal product and average product per kg of chemical fertilizer sharply decreases with increased consumption of chemical fertilizer per *mu*. To improve the forecasting accuracy, it is therefore necessary to construct nonlinear forecasting equations.

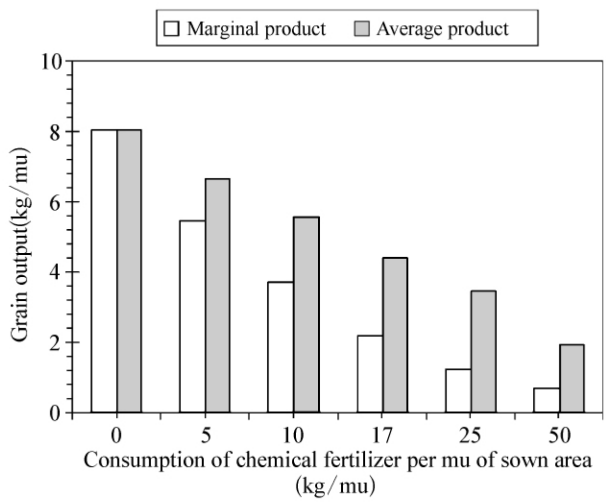

Fig. 1 Marginal product and average product per kg of chemical fertilizer in China

Using econometric techniques, we have so far established 20 alternative forecasting equations on grain output and grain yield with a high degree of accuracy. In these forecasting equations, either grain yield or grain output is the dependent variable. Every year, the forecasting performance of all equations is checked on the basis of the actual grain output or yield of the preceding year. The equations that exhibit very large errors are taken out and the average forecast of the remaining equations (with the same dependent variable) is used as the final prediction result.

The explanatory variables of these equations include some of the following variables: total area of cultivated land; total sown area of farm crops; total sown area of grain crops; the grain price; the price of other farm crops; the price of fertilizers; net income of grain crops per *mu*; net income of other farm crops per *mu*; the ratio of areas hit by natural