Estimation of Agricultural Production Relations in the LUC Model for China

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Abstract

China's demand for grains has been growing rapidly during the past two decades, largely as a result of the increasing demand for meat. This raises the important question of whether in the coming years China will be able to satisfy these increasing needs. The answer to this question will have implications that reach far beyond China's borders, especially in light of China's accession to the World Trade Organization (WTO). The answer depends on many factors, including the policy orientation of the Chinese government, the loss of cropland caused by the ongoing industrialization and urbanization processes, and the effect of climate change on the country's agricultural potential.

To analyze these issues, the Land-Use Change (LUC) Project at the International Institute for Applied Systems Analysis (IIASA) has been developing an intertemporal welfare-maximizing policy analysis model. This report presents the input–output relationships for agricultural crops in the model. The specified relationships are geographically explicit and determine the crop output combinations that can be achieved under the prevailing biophysical conditions across China from given input combinations in each of some 2,040 counties based on data for 1990. The non-land inputs are chemical and organic fertilizer, labor, and machinery. Irrigated land and rain-fed land are distinguished as separate land-use types. Distinct relationships are estimated by cross-section for the eight economic regions distinguished in the LUC model. The biophysical potential enters as an asymptote in a generalized Mitscherlich–Baule yield function and is computed on the basis of an agro-ecological assessment of climatic and land resources, including irrigation. The chosen form globally satisfies the required slope and curvature conditions.

Estimation results show that all key parameters are significant and are of the expected sign. The calculated elasticities of aggregate output with respect to inputs quite closely reflect the relative scarcity of irrigated land, labor, and other inputs across the different regions. It also appears that if both the local population density and the distance to main urban centers are taken into account, the observed cropping patterns are generally consistent with profit maximization. The often-noted labor surplus is confirmed in all regions, particularly in the southern and southeastern regions.

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1 Introduction

Rapid economic growth has stimulated China's demand for food and feed grains. While the country has an impressive record of increasing its agricultural production, it is not clear to what degree China can or should maintain food self-sufficiency. Nor is it clear whether eventually a significant share of imports should consist of meat or feed grains. The answers to these questions are not only important for China, but have strong implications for world markets as well. In its *World Food Prospects*, the International Food Policy Research Institute (IFPRI) anticipates that between 1995 and 2020, China alone will account for one-quarter of the global increase in demand for cereals and for two-fifths of the increase in demand for meat (Pinstrup-Andersen *et al*., 1999).

However, China's successful economic development has itself created new room for choice, and future developments may depart significantly from the historical trend. Based on this recognition, the Land-Use Change (LUC) Project at the International Institute for Applied Systems Analysis (IIASA) has selected an approach that seeks to identify alternative options for agricultural policy through a spatially explicit, intertemporal welfare-maximizing model.[1] This model takes into account the main biophysical restrictions in the various parts of China, as well as the main socioeconomic factors that drive land-use and land-cover change (Fischer *et al*., 1996).

This report documents the specification of the input–output relationships for crop production and presents the estimation procedure and results. These relationships describe the crop output combinations that can be produced from given combinations of chemical and organic fertilizers, labor and traction power, and irrigated and rain-fed land. Descriptions are made for each of some 2,040 counties in China for the year 1990 based on prevailing environmental conditions (i.e., climate, terrain, soils). The relationships are estimated separately for the eight economic regions distinguished in the LUC model.[2] In addition to these input–output relations for crop production, the LUC model also contains components for livestock production, consumer demand, land conversion, and water development. These will be presented in separate reports.

Several estimates of agricultural production functions for China exist in the literature. In general, the primary focus of these studies was assessing the level of the total factor productivity and its change, estimating the marginal productivity and output elasticities of the main production factors, and evaluating the specific contribution of rural reform to agricultural growth. On the basis of pooled data at the provincial level, Lin (1992) assessed the contributions of decollectivization, price adjustments, and other reforms to China's agricultural growth in the reform period. Lin estimates that decollectivization accounted for about half the output growth during the period from 1978 to 1984. Wiemer (1994) uses micro panel data from households and production teams in a rural township to analyze the pattern of rural resource allocation before and after the reform. Both studies apply a Cobb–Douglas form to specify an agricultural production function with four conventional inputs: land, labor, capital, and chemical fertilizer (or intermediate inputs). Additional variables needed for specific assessment purposes are incorporated into the exponential term of the Cobb–Douglas form.

Two recent studies by Carter and Zhang (1998) and Lindert (1999) incorporate climate and biophysical information in addition to the conventional inputs. Carter and Zhang estimate grain production using a Cobb–Douglas model for the five major grain-producing regions in China with aridity indices using data for the period from 1980 to 1990. Lindert estimates the agricultural and grain productivity for both North and South China with a mixed translog and Cobb–Douglas specification using soil chemistry indices from soil profiles and input–output data at the county level. In both studies fertilizer input is limited to chemical fertilizer, although in Lindert's study the manure aspect is implicitly incorporated via an *organic matter* index.

Zhang and Fan (2001) employ a generalized entropy approach and provincial panel data to estimate a multi-output technology at the national level. Three aggregate outputs (grain crops, cash crops, and other agricultural activities) and five inputs (land, labor, chemical fertilizer, machinery, and draft animals) are incorporated in the estimate. Under the strong assumption that the marginal returns of non-land inputs among three major agricultural activities must be equal, Zhang and Fan try to recover the unknown input allocations among the three activities. While this assumption might be plausible across the two crop activities, it may not hold up across cropping and non-cropping activities. This effort is constrained by several caveats inherent in the maximum entropy approach, as noted by the authors.

Including the crop input–output relationships within the wider LUC welfare model imposes various requirements. First, an adequate representation of environmental conditions relevant to agricultural land-use patterns should be reflected in the LUC model. To ensure this, the biophysical potentials, as computed from an agro-ecological assessment, were included in the crop production function in a form that fits meaningfully within the economy-wide model. The potentials enter through the vector of land resources and a maximal yield that serves as an asymptote to actual yields. The building blocks for the potential output calculation are county-level potential yields for different land types (irrigated and rainfed) and for major seasonal crops (e.g., winter and summer crops corresponding to relevant Asian monsoon seasons in China). These county-level potential yields were compiled in the LUC Project's land productivity assessment component based on experience gained from site experiments employing detailed crop process models (Rosenzweig *et al.*, 1998) and applying a China-specific implementation of the enhanced agro-ecological zones (AEZ) methodology (Fischer *et al.*, 2002). The AEZ assessment is a well-developed environmental approach that provides an explicit geographic dimension for establishing spatial inventories and databases of land resources and crop production potential. The method is comprehensive in terms of its coverage of factors affecting agricultural production, such as components of climate, soil, and terrain. It takes into account basic conditions in supply of water, energy, nutrients, and physical support to plants. The AEZ method makes maximum use of the available information. Moreover, it can also be used to assess changes in production potential in response to scenarios of climate change.

Second, the functions must satisfy global slope and curvature conditions (i.e., convexity for the output index and concavity for the input response function). These conditions were met through restrictions on the relevant function parameters.

Third, the estimates must accommodate the limitations of the available information. For instance, no data were available on crop-specific inputs, such as fertilizer applied to wheat. This lack of information is not specific to China, but is fairly common in agricultural sector modeling, which makes it impossible to identify the parameters of separate crop-specific production functions. The usual approach is to represent the technology via a transformation function with multiple outputs jointly originating from a single production process with multiple inputs. Under the assumption of revenue maximization, this approach enables identification of derived net output functions separately by commodity (see, e.g., Hasenkamp, 1976; Hayami and Ruttan, 1985). These functions use output and input prices and resource levels (land, labor, and capital) as dependent variables. However, in the case of China, two special difficulties limit the applicability of this approach. First, despite the decollectivization in the 1980s, decision making concerning farm operations has not yet been left to individual farm households, and various rules and regulations are still in effect that do not find expression in farm-gate prices and are not formally recorded. The data used in our study are from the year 1990, when even more decisions were made at the village government level than is currently the case. Second, the only available output price data are (weighted average) state procurement prices for major crops at the provincial and national levels; no published input price data are available. To overcome these obstacles, the transformation function had to be estimated directly in its primal form. Yet, to investigate the degree to which the prevailing allocations could be interpreted as resulting from a profit-maximization model, we compute and compare the implicit prices that would support observed allocations under profit maximization.

This report is organized as follows. Section 2 describes the basic institutional features of the agricultural sector in China after the reform in 1979, including the land tenure system; crop pricing and marketing; basic production technology; and the level of autonomy of farm households in making decisions regarding production, marketing, and resource allocation. Section 3 provides the specification of the transformation function. Section 4 describes the data used for estimation, including preparatory compilations and adjustments. The estimation results and their implications in terms of elasticities, spatial distributions, and implicit prices are presented in Section 5. A summary and conclusions are provided in Section 6. Two appendices report on the numerical implementation of the estimation procedure and the formulae for elasticity calculations.

Notes

All the authors provided specific contributions to the writing of this report. Günther Fischer and Laixiang Sun compiled the database. Fischer developed the agro-ecological assessment model for China and estimated the biophysical potentials. Sun and Peter Albersen estimated the input response function. Albersen also estimated the output function; performed the final, joint estimation of the output and input components; and computed the implicit prices. Michiel Keyzer provided general guidance and technical advice.

[1] IIASA and the Centre for World Food Studies, Free University (SOW-VU), Amsterdam, are cooperating in the construction of the LUC model.

[2] The eight economic regions distinguished in the LUC model are as follows: *North*, including Beijing, Tianjin, Hebei, Henan, Shandong, and Shanxi; *Northeast*, including Liaoning, Jilin, and Heilongjiang; *East*, including Shanghai, Jiangsu, Zhejiang, and Anhui; *Central* including Jiangxi, Hubei, and Hunan; *South*, including Fujian, Guangdong, Guangxi, and Hainan; *Southwest*, including Sichuan, Guizhou, and Yunnan; *Northwest*, including Nei Mongol, Shaanxi, Gansu, Ningxia, and Xinjiang; and *Plateau*, representing Tibet and Qinghai.

2

Transformation of the Agricultural Sector, 1979 to 1999

In 1979, China initiated a dramatic reform of the institutional structure of its agricultural sector. China's agricultural system was changed from one based on collectives to one in which decisons regarding inputs and most outputs are made by individual farm households. As a rule, the new family farms are small and fragmented, and depend heavily on irrigation. Thus, Chinese farmers are induced to save land and capital and to opt for highly labor-intensive practices. In this section, the main elements of this transformation process are reviewed.

2.1 Institutional Arrangement of China's Family Farms in the Post-Reform Era

During the period from 1979 to 1983, collective farming was replaced by the household responsibility system (HRS). Under the HRS, individual households in a village are granted the right to use the farmland for 15 to 30 years; the village community, via its government, retains other rights associated with ownership of the land. This land tenure system constitutes a two-tier system with use rights vested in individual households and ownership rights vested in the village community (Kung, 1995; Dong, 1996).

Unlike under the previous collective system, under the new land tenure system farm households are independent production and accounting units. Each household can independently organize its production and exercise control over output and production. Most important, the control rights to residual benefits are assigned to individual households. A fraction of the crop is still sold to the state via state procurement requirements at prices below the free-market level, and another fraction is delivered to the village government as payment for rent or taxes and as a contribution to the village welfare and accumulation funds. The remainder is left with the households for consumption, saving, or selling on the free market. The right to use land also entails an obligation to contribute labor for maintenance and construction of public infrastructure. The village governments in the HRS also manage land contracts, maintain irrigation systems, and provide agricultural services such as large farm machinery rental, product processing, marketing, and technological advice and assistance (World Bank, 1985; Wen, D., 1993; Lin, 1997).

When the HRS was introduced, collectively owned land was initially contracted to each household in short leases of one to three years. In the distribution of land, egalitarianism was generally the guiding principle. Most villages have leased land to their member households strictly on the basis of family size rather than intra-household labor availability. Moreover, for the initial distribution, land was first classified into different grades. Thus, a typical farm household would contract 0.56 hectares (ha) of land divided into 9.7 tracts (Dong, 1996; Lin, 1997). The one- to three-year contract was eventually found to discourage investment in land improvement and soil fertility conservation. Further reforms were initiated and the duration of the contract was extended to 15 to 30 years. As a result, various models of the land tenure system have evolved in different regions, adapting to local needs and conditions.[1]

2.2 Pricing and Marketing of Agricultural Products

During the establishment of the HRS, increasing emphasis was placed on market mechanisms for guiding production decisions in the agricultural sector, although central planning was still deemed essential. The numbers of planned product categories and mandatory targets were reduced from 21 and 31, respectively, in 1978 to 16 and 20, respectively, in 1981, and further to 13 each in 1982. Moreover, restrictions on interregional trade of agricultural products by private traders were gradually loosened. Cropping patterns that fit local conditions and exploited comparative advantages were encouraged. Consequently, both cropping patterns and intensity changed substantially between 1978 and 1984. The sown acreage of cash crops increased from 9.6% of the total in 1978 to 13.4% in 1984, and the multiple-cropping index declined from 151 to 147 (Lin, 1997: table 3).

The second round of market reforms was initiated in 1985. The central government announced that the state would no longer set any mandatory production plans in agriculture and that the obligatory procurement quotas were to be replaced by purchasing contracts between the state and farmers (Central Committee of CCP, 1985). Although the progress of this market reform has been slower than and not as smooth as expected, the market freedom enjoyed by Chinese farmers has increased significantly. In the early 1990s about one-third of China's marketable cereal production was sold at free-market prices and another third was procured by government agents at negotiated prices. The gap between market prices and quota prices has gradually narrowed, although the pace has been slow and uneven. The production and marketing of vegetables, fruits, and most cash crops have been fully liberalized since 1985.

2.3 Dependence on Irrigation

About half of China's farmland has been under some form of irrigation since the 1980s.[2] The irrigated land produces about 70% of China's grain output and most of its cotton, cash crops, and vegetables. Thus, heavy dependence on irrigation is another unique feature of China's agricultural sector. This contrasts sharply with the situation in other major agricultural world regions. For instance, in the United States, only one-tenth of the grain output comes from irrigated land (Brown and Halweil, 1998). While most of the irrigation water is delivered to the fields by gravity irrigation with the help of dams, reservoirs, canals, and irrigation systems, an increasing portion is being supplied by diesel and electric pumps. Machine-powered irrigation was used in one-quarter of the total irrigated area in 1965, increasing to two-thirds in 1993 (SSB, 1993:349; Ministry of Water Conservation, 1994). Consequently, irrigation equipment has accounted for a large fraction of the total power consumed by agricultural machinery since the 1980s.

2.4 Labor-Intensive Production

It is generally accepted (Wen, D., 1993; Wang, 1998; Lindert, 1999) that land is an extremely scarce factor in China's agricultural sector, while capital is limited and labor is relatively abundant. The percentage of the labor force employed in the agricultural sector has been gradually falling, decreasing from 93.5% in 1952 to 56.4% in 1993. However, because of rapid population growth, the total number of agricultural workers doubled during the same period, increasing from 173 million in 1952 to 374 million in 1993. This increase occurred despite the rapid expansion of the rural industrial sector, which has created employment for more than 120 million rural workers since 1992. The growth in the absolute number of farm workers in the cropping sector persisted until 1984, and this trend persisted in the agricultural sector as a whole until 1993 (Lin, 1992: table 4; SSB, 1997:94, 400). In 1990, the average family farm managed only 0.42 ha of farmland but employed 1.73 laborers (Ministry of Agriculture, 1991).

Constrained by the unfavorable land/labor ratio, Chinese peasants have historically had to adopt a number of labor-intensive, land-saving, and yield-increasing technologies, such as intensive use of organic and chemical fertilizers, irrigation development, use of plastic film to cover fields, rapid adoption of new crop varieties such as hybrid rice, sophisticated cropping systems, and high levels of multiple cropping. Most of the land-saving technologies increase the need for application of nutrients and other farm inputs.

Organic fertilizer has always been central to traditional, small-scale Chinese farming. Farmers commonly use a wide variety of organic fertilizers, including night soil (i.e., human excrement), animal manure, oil cakes, decomposed grasses and household wastes, river and lake sludge, and various green manures. Night soil and animal manure have been the most important sources because of their high nutrient content and low cost.[3]

Chemical fertilizers increasingly have been used to improve crop yields because of the rapid growth of both domestic fertilizer production capacity and fertilizer imports. Chemical fertilizer use in China has quadrupled since 1978. Since the early 1990s, China has emerged as major importer and the largest consumer and producer of chemical fertilizers in the world (FAO, 1989–1997; SSB, 1989–1997). However, the average application of chemical fertilizer in China has remained modest, staying near the 1995 level of 155 kilograms of nutrients per ha, which is below the average level of East Asian developing countries and far below levels used in Japan and South Korea.[4] According to estimates by the World Bank (1997:16), with an estimated value of 125 billion yuan, fertilizer applied to crops was the largest cash input in crop production in 1995. The rapidly increasing application of chemical fertilizer has been identified by many as a key contributing factor to the significant productivity growth in China's agricultural sector over the past three decades. Many studies suggest that the overall yield response to chemical fertilizers has been significant (e.g., Kueh, 1984; McMillan *et al*., 1989; Halbrendt and Gempesaw, 1990; Lin, 1992), partly through the mutual reinforcement of increasing application of chemical fertilizers and adoption of new crop varieties responsive to chemical fertilizers.

Two recent quantitative estimates suggest that chemical fertilizer application has increased much faster than application of organic fertilizer since the early 1970s, and that chemical fertilizers have been the dominant nutrient source since 1988 (Agricultural Academy of China, 1995: chapter 8) or 1982 (Wang *et al*., 1996). However, because of low quality and inefficient methods of chemical fertilizer application, about half the nitrogen applied to irrigated land is lost to evaporation (World Bank, 1997:18), leaching, and emissions, leaving much room for efficiency gains.

It should also be noted that organic fertilizer is more than a mere substitute for chemical macro nutrients. With its high content of organic matter and wide range of crop macro and micro nutrients, organic fertilizer improves soil structure and fertility in the long run. Thus, it is believed that organic fertilizer should complement chemical fertilizer and improve its effectiveness. Also, organic fertilizer is applicable to rain-fed land without preconditions, whereas the application of chemical fertilizer is constrained by the timing of water supply. Finally, the tradition of careful use of organic fertilizers made the transition to chemical fertilizers relatively smooth and easy in China in the 1960s and 1970s (Stone and Desai, 1989).

Notes

[1] For more information on various innovative models of land tenure, see, for example, Wang (1993), Chen and Han (1994), Rural Sample Survey Office (1994), Lin (1995). Dong (1996), and Fahlbeck and Huang (1997),

[2] There are two sets of farmland data in China. The most widely used is the data set published by the National Bureau of Statistics (NBS) in the *Statistical Yearbook of China*. Another data set was compiled by the State Land Administration (SLA), based on a land survey conducted in the 1980s. NBS has noted that its figures for cultivated areas may underestimate the actual extent. According to NBS, China had 95.7 million ha of cultivated and 47.4 million ha of irrigated land in 1990, whereas the corresponding figures from the SLA were 132.7 and 63.5 million ha, respectively. While the irrigation shares are similar on average, the differences between the estimates at the provincial and national levels are quite large (SSB, 1994, pp. 329 and 335; Fischer *et al*., 1998).

[3] It should be noted that econometric studies may underrate the role played by organic fertilizer because relevant statistical data are often lacking and, where available, they exhibit high correlation with total labor input.

[4] This rate is calculated on the basis of the SLA's figure of the total farmland area, which is about 132 million ha for 1995. The SLA's farmland figure is based on a detailed land survey conducted from 1985 to 1995 and is consistent with estimates derived from satellite imagery (see also Fischer *et al*., 1998).

3

Agricultural Production Relationships

Our specification of the agricultural production relationships is based on that of Keyzer (1998). We postulate a transformation function that can be separated into outputs and inputs, with a crop-mix index for outputs and a response function for inputs. The crop-mix index is in constant elasticity of substitution (CES) form and the input response is specified as a generalized version of the common Mitscherlich–Baule (MB) yield function, whose maximum attainable output is obtained from an agro-ecological zone assessment. The input response distinguishes two types of land: irrigated and rain-fed. Their yield potentials and cropping practices differ significantly. However, since, as is usual in agricultural sector modeling, the data on inputs are not differentiated by type of land use or by crop, and since data on crop output are not land-use-type specific, we cannot estimate a transformation function for each land type or crop separately. Rather, a single transformation function is applied for all crops and land-use types.

3.1 Overview of the Transformation Function

Let the subscript l denote observations (i.e., more than 2,000 counties in this case); Y, an $l \times C$ matrix of outputs; V, an $l \times K$ matrix of non-land inputs; and A, an $l \times S$ matrix of land uses with S different land types. The $l \times N$ matrix of natural conditions, including climate, soil, and terrain characteristics, is denoted by x. We postulate a transformation function $T(Y, -V, -A, x)$ that is taken to be quasi-convex, continuously differentiable, non-decreasing in $(Y, -V, -A)$, and linear homogeneous in (V, A). The function T describes all possible input–output combinations. To ease estimation, separability is assumed between inputs and outputs:

$$T(Y, -V, -A, x) = Q(Y) - G(V, A; x)\,, \tag{3.1}$$

where $Q(Y)$ is the crop-mix index and $G(V, A; x)$ is the input response function. Function $Q(Y)$ is taken to be linear homogeneous, convex, non-decreasing, and continuously differentiable; $G(V, A; x)$ is taken to be linear homogeneous, concave, and non-decreasing in (V, A), and continuously differentiable. This implies that the transformation function T is convex and non-increasing in net outputs. The interpretation of this transformation function is as follows: under natural conditions x, the given input and land availabilities (V, A) make it possible to produce a quantity G of the aggregate production index Q with any crop mix such that $Q(Y) = G$.

The input and output variables are measured in quantity terms and are compiled by county. As discussed earlier, the transformation function is estimated in the primal form rather than in the dual form with separate crop-specific supply functions. This is done for two reasons. First, profit maximization may not be an appropriate behavioral criterion for Chinese agriculture. Second, price data cannot capture the variability at the county level, as they are only available at the provincial level and are measured as a mix of procurement prices and free-market prices. The estimate is based on a cross-section of counties, in volumes per unit area (represented by the lower-case characters); that is,

$$q(y) = g(v, a; x) + \varepsilon \ , \tag{3.2}$$

where ε denotes the error term, assumed to be independently and normally distributed. The estimation procedure and results are discussed in Section 4.

3.2 Crop-Mix Output Index

The crop-mix output index $Q(Y)$ is specified as a convex function with CES:

$$Q(Y_l) = (\sum_c (\alpha_c Y_{l_c})^{\alpha_0})^{1/\alpha_0} \ , \tag{3.3}$$

where $\alpha_c \geq 0$ and $\alpha_0 > 1$. The curvature of the output function, or the (direct) elasticity of transformation between any two outputs, equals $1/(1-\alpha_0)$. The restriction $\alpha_0 > 1$ ensures that the CES function will be convex.

The specification also needs to be flexible to account for different cropping patterns in different counties – say, for a county where only 10 of the 16 crops are being grown. This could be incorporated in various ways. One way would be to drop the crops not being grown from the crop-mix index while scaling up the coefficients for the remaining crops in Equation (3.3) through an additional parameter. However, in doing this we face the problem that the number of observations is often insufficient for conducting a meaningful estimation capable of taking into account every existing crop mix. Moreover, two to four crops often account for about two-thirds of the total production value. To deal with this problem, we distinguish between major and minor absent crops and associate a limited number of scaling factors to the production function of a particular county, depending on the number and importance of the absent crops. Consequently, Equation (3.3) becomes

$$Q(Y_l) = (1 + \sum_m \mu_m M_{lm})(\sum_{c \in C_l} (\alpha_c Y_{lc})^{\alpha_0})^{1/\alpha_0} \ , \tag{3.4}$$

where μ_m is an estimated scaling factor, M_{lm} is a zero-one dummy that associates the county with a particular scaling factor, and C_l is the set for which $Y_{lc} > 0$. Each county has at most one nonzero crop-mix dummy. Further details on the association rule are given in Section 4.

3.3 Input Response Function

The input response function combines the information obtained from biophysical assessments with the statistical data available at the county level. It is specified as

$$Q_l = f\left(V_l, H(A_l)\right)\ N\left(A_l, \overline{y}_l(x_l)\right)\ , \tag{3.5}$$

where $f(.)N(.)$ is a generalized MB specification based on Keyzer (1998), and $H(.)$ and $N(.)$ are the aggregate area and potential output index, respectively, which are specified as

$$H_l(A_l;\delta) = \sum_s \delta_s A_{ls}\ , \tag{3.6}$$

$$N_l(A_l, \overline{y}_l(x_l);\delta) = H_l(A_l;\delta)\overline{y}_l(x_l)\ , \tag{3.7}$$

with $\overline{y}_l(x_l)$ denoting the maximum attainable yield for given agro-ecological conditions x_l. This potential yield $\overline{y}_l(x_l)$ is calculated as the maximum attainable production $\overline{Y}_l(x_l)$ divided by land index H_l. Parameter δ_s is preset and was not estimated. The input response function $f(.)$ in Equation (3.5) is specified in product form to allow for different input groups. The functional form is

$$f\left(V_l, H(A_l)\right) = \prod_j f_j(V_l, H_l; \beta_j, \gamma, \rho_j)^{\theta_j}\ , \tag{3.8}$$

with

$$f_j = 1 - \exp[-\beta_j - w_j(V_l, H(A_l;\delta);\gamma,\rho_j)]\ , \tag{3.9}$$

where f_j is the jth component of an MB yield function, and its exponent $\theta_j > 0$ is such that $\sum_j \theta_j = 1$. This parameter θ_j avoids the increasing returns that would result from the standard MB form with $\theta_j = 1$. In addition, a nested structure is assumed for inputs to ease the nonlinear estimation. In Equations (3.8) and (3.9), index j stands for two categories of inputs, *power* and *nutrients*. Power consists of labor and agricultural machinery. Nutrients includes chemical and organic fertilizers. For both categories we assume a CES form, denoted by w_j:

$$w_j(V_l, H(A_l;\delta);\gamma,\rho_j) = \left(\sum_{k\in j}\gamma_k\left(\frac{V_{lk}}{H_l}\right)^{\rho_j}\right)^{1/\rho_j}\ , \tag{3.10}$$

with $\gamma_k \geq 0$ and $\rho_j \leq 1$ ensuring the concavity of $w(.)$. Input response function (3.5) is linear homogeneous, globally concave and non-decreasing in (V, A), and continuously differentiable.

The biophysical diversity across China is reflected in the potential yield $\overline{y}_l(x_l)$, as explained in Section 4. However, cropping possibilities vary widely across China and within the estimated regions, ranging from single cropping to triple rice cropping. The maximum attainable yield $\overline{y}_l(x_l)$ alone is not sufficient to capture this variability. To account for these differences, cropping system zone variables Z_{lz} are introduced, where the subscript z indicates the cropping system zone. If a county is located in cropping system zone z, the value of the related variable is 1, otherwise it is 0. Then Equation (3.5) becomes

$$Q_l = Z_z f\left(V_l, H(A_l)\right) N\left(A_l, \overline{y}_l(x_l)\right) \ , \tag{3.11}$$

with

$$Z_z = \sum_z \zeta_z Z_{lz} \ . \tag{3.12}$$

The outputs in Equation (3.4) and the potential production in Equation (3.5) are measured in different units: Y_{lc} is given in metric tons of produce, while the potential is given as cereal equivalent in metric tons of dry matter. Harmonization of the measurement is restored via the crop- and county-specific parameter ratio $\alpha_c(1 + \mu_m M_{lm})/\zeta_z Z_{lz}$.

3.4 Computing Implicit Prices for Aggregation

The transformation function enters the LUC welfare model for China after a procedure to aggregate from the county to the regional level. Our approach is to assume “implicit” profit maximization at implicit prices – the prices that would support the observed crop and input allocations under profit maximization. Such prices are necessary for aggregating county-level behavior to the regional level. The difference between these computed prices and the observed average market prices in the cities could be interpreted as a measure of the processing and trade margins if this condition applied. However, this interpretation is oversimplified, as discussed in Section 2.2. Part of the production corresponding to quota procurement might not react to marginal signals. The production quotas and possibly also the negotiated procurement would be introduced into the production system – for example, as committed production – leaving the marginal calculation to the production linked to the free-market trade. This requires additional county-level information that is not available at present and is thus beyond the scope of the current report. Hence, the implicit prices to be calculated in Section 5.5 represent only a preliminary investigation of a spatial pattern of margins under the profit-maximizing hypothesis, neglecting all rationing.

The separable transformation function (3.1) ensures separability between output and input decisions. The farmer determines the crop mix so as to maximize the revenue corresponding to a given value of the index Q, while choosing the level of inputs V so as to minimize his costs at given prices of V and output Q.

Thus, the crop-mix problem of the revenue-maximizing farmer with given output index $\overline{Q}_l$ is stated as

$$\begin{aligned} \max_{Y_{lc}\geq 0} \quad & \sum_{c\in C_l} p_{lc} Y_{lc} \\ \text{s. t.} \quad & Q(Y_l) = \overline{Q}_l \ , \end{aligned} \tag{3.13}$$

with p_{lc} as the price of crop c in county l. The Lagrangean of this problem is

$$L = \sum_{c\in C_l} p_{lc} Y_{lc} - \overline{P}_l (Q(Y_l) - \overline{Q}_l) \ , \tag{3.14}$$

where the Lagrangean multiplier is the county-level price index $\overline{P}_l$, since the function $Q(Y_l)$ has constant returns to scale. The first-order conditions of this problem determine the implicit (shadow) prices of crop $c \in C_l$:

$$p_{lc} = \overline{P}_l \frac{\partial Q(Y_l)}{\partial Y_{lc}} = \frac{\overline{P}_l \overline{Q}_l}{Y_{lc}} \frac{(\alpha_c Y_{lc})^{\alpha_0}}{\sum\limits_{c'} (\alpha_{c'} Y_{lc'})^{\alpha_0}} . \tag{3.15}$$

For the base year, the county-level price index $\overline{P}_l$ has been calculated from provincial and national prices and county-level production data (see Appendix A). In simulation runs with endogenous crop prices p_{lc}, the index is calculated as

$$P_l = \frac{1}{(1 + \sum\limits_m \mu_m M_{lm})} \left(\sum_{c\in C_l} \left(\frac{p_{lc}}{\alpha_c} \right)^{\sigma} \right)^{\frac{1}{\sigma}} \ , \tag{3.16}$$

with $\sigma = \frac{\alpha_0}{\alpha_0 - 1}$. The county-specific relation between the base year price index and the index obtained under the maximizing-producer assumption becomes

$$\overline{P}_l = P_l (1 + \varepsilon_l^p) = P_l (1 + \frac{\overline{P}_l - P_l}{P_l}). \tag{3.17}$$

In simulation runs the estimated price index can replace the "observed" index.

Finally, for the input side the restricted profit-maximization problem becomes

$$\max_{V_{lk}\geq 0, A_{ls}\geq 0} \ \overline{P}_l G(V_l, A_l) - \sum_k p_{lk} V_{lk} - \sum_s p_{ls} A_{ls} \ . \tag{3.18}$$

The first-order condition with respect to input k of group j gives the marginal productivity:

$$p_{lk} = \overline{P}_l \frac{\partial G(V_l, A_l)}{\partial V_{lk}} = \overline{P}_l \frac{\partial g(v_{lk})}{\partial v_{lk}} , \tag{3.19}$$

with $v_{lk} = V_{lk}/H_l$ and

$$\frac{\partial g(v_{lk})}{\partial v_{lk}} = g_l \theta_j \frac{1 - f_{lj}}{f_{lj}} w_{lj}^{1-\rho_j} \gamma_k v_{lk}^{\rho_j - 1} . \tag{3.20}$$

For land-use type s, the marginal productivity is

$$\begin{aligned} p_{ls} &= \overline{P}_l \frac{\partial G(V_l, A_l)}{\partial A_{ls}} = \overline{P}_l \left(f_l \frac{\partial N(A_{ls})}{\partial A_{ls}} + N_l \frac{\partial f(V_l, A_{ls})}{\partial A_{ls}} \right) \\ &= \overline{P}_l \delta_S g(v_l) \left(1 - \frac{\partial g(v_l)}{\partial v_l} \frac{v_l}{g(v_l)} \right) , \end{aligned} \tag{3.21}$$

where

$$\frac{\partial g(v_l)}{\partial v_l} \frac{v_l}{g(v_l)} = \sum_j \theta_j \frac{1 - f_{lj}}{f_{lj}} w_{lj} \tag{3.22}$$

and f_{lj} and w_{lj} are as defined by Equations (3.9) and (3.10).

4

Data: Sources, Adjustments, and Qualifications

Despite major improvements in the quality and availability of relevant statistics for China, various procedures had to be applied to scrutinize data, fill data gaps, and define proxy variables. These procedures and variables are discussed in this section.

4.1 Crop Outputs and Procurement Prices

The total annual output of grain, cotton, and oilseeds is available at the county level (SSB and CDR, 1996). The published data were matched with the county administrative codes used in the LUC Project's database for China. Also available are output data and data on sown areas of wheat, rice, maize, sorghum, millet, other starchy crops, potato and other root crops, soybeans, oilseeds, cotton, sugar beet, sugarcane, fiber crops, tobacco, tea, and fruit for 1989. Detailed data on crop distribution were not available for 1990. The data were compiled by China's State Land Administration (SLA) and provided to the Food and Agriculture Organization of the United Nations (FAO). Whereas the 1989 crop was quite poor owing to weather conditions, the 1990 crop is highly representative of the average conditions of Chinese cropping agriculture during the period from 1985 to 1995; thus we use data for 1990 whenever possible. Consequently, we had to disaggregate the data for grains in 1990 on the basis of the crop-pattern distribution available for 1989. According to Chinese statistics, the aggregate termed "grains" includes wheat, rice, maize, sorghum, millet, other starchy crops, potatoes and other root crops, and soybeans (five kilograms of potatoes and other root crops are counted as one kilogram of grain; all other commodities have a conversion factor of unity). For sugarcane, fiber crops, tobacco, tea, and fruits, the 1989 outputs had to be used.

Thus, crop outputs in 1990 were estimated as

$$q_c^{90} = G^{90} \cdot \frac{q_c^{89}}{G^{89}} , \tag{4.1}$$

where G^t is total grain output in year t and q_c^t is crop-specific output measured in grain equivalent.

For vegetables, only estimates of sown areas at the county level were available for 1989, and no output data were available for any year. The national average yield of 20.9 tons/ha in 1989 was used to calculate vegetable output at the county level (Xie and Jia, 1994:103).

Procurement prices at both the provincial and national levels for wheat, rice, maize, sorghum, millet, soybeans, oilseeds, cotton, sugarcane, fiber crops, tobacco, tea, and fruit were extracted from the *Yearbook of Price Statistics of China 1992* (SSB, 1992b:302–365). The procurement price for a crop is the quantity-share-weighted mean of quota prices, negotiated prices, and free-market prices. Commodities are procured not only by government agencies, but also by enterprises, social organizations, and trade companies. There are no price data for Hainan province in this *Yearbook*. Prices in Guangdong were used as proxies for those in Hainan in view of the fact that Hainan province was a prefecture of Guangdong until 1988. No price data are available for the aggregate of other starchy crops. The price of maize is used as a proxy in each province according to the information in the national price data for China listed in the FAO-AGROSTAT database. Again with reference to FAO-AGROSTAT, one-third of the wheat price is used as a proxy for the price of potatoes and other root crops in each province.

Prices of vegetables were compiled from *Nationwide Data on Costs and Revenues of Agricultural Products 1991* (Eight Ministries and Bureaus, 1991). The prices listed in this publication are free-market selling prices of major vegetables shown for selected major cities (typically the provincial capital city) in most of the provinces. Representative vegetables were selected for each province, and the representative price for the vegetable category is the arithmetic mean of the various prices.

Using the process described above, price data were obtained for all major crops of each province. However, price information was still missing for some minor crops that are actually the main crops in some counties. To fill these gaps, a corresponding price was used from one of the neighboring provinces with similar production conditions. When no such province was available, the national average price was used as a proxy.

In the compilation of the initial output index Q, the provincial prices were applied directly to the county level, ignoring all price differences across counties within each province.

4.2 Non-Land and Land Inputs

Data on non-land inputs used in the broad agricultural sector at the county level are available from the LUC Project for various years between 1985 and 1994. They include agricultural labor force, total power of agricultural machinery, total number of large animals, and chemical fertilizer applied. Here, we discuss only the 1990 data, since these were the data used in the estimation. A data problem arises from the fact that, in Chinese statistics, broad agriculture comprises farming, forestry, animal husbandry, fishery, and sideline production. We attribute non-land inputs to the crop sector based on the share of cropping agriculture in broad agriculture. The total output value of broad agriculture is available at the county level. The availability of crop output data enables us to calculate the total output value of cropping agriculture for each county by straight aggregation over crops valued at provincial prices. The resulting shares are applied to the agricultural labor force and power of agricultural machinery.[1]

Two remarks are in order. First, the approach is questionable for counties where the share of cropping agriculture is minor or where agricultural workers or machinery are in fact used for non-agricultural activities. In some suburban counties the number of agricultural workers per hectare of agricultural land is extremely high (greater than 10). Machine power per hectare is likewise biased because transport vehicles and other processing machineries are included in the statistics. Nonetheless, these counties were initially included in the estimates. After the first round, some of the counties biased the estimation substantially, and these observations were dropped. Second, prices are at the provincial level; consequently, the variability at the county level depends on quantities alone.

"Chemical fertilizer applied" can safely be attributed to crop farming rather than to forests or pastures. Organic fertilizer data have to be derived indirectly. We follow the approach used by Wen (Wen, G.J., 1993: tables 4 and 5) and assume the following:

- One person produces 0.5 tons of night soil per year on average; the utilization rates of night soil in the rural and urban areas were 0.8 and 0.4, respectively, in 1990; the nutrient content rate of night soil is 0.011 (i.e., 1.1%).
- A large animal produces 7.7 tons of manure per year on average; the utilization rate is 0.8; the nutrient content rate is 0.0102.
- Hog manure is assumed to be produced at a rate of 2 tons per animal per year, with a utilization rate of 0.8 and a nutrient content rate of 0.014.

No systematic data are available on other sources of organic fertilizer, such as green fertilizer, oil cakes, compost, and mud and pond manure. The resulting estimate of the national total of 17.5 million tons of organic fertilizer supply is 6 million tons lower than Wen's 1989 figure, but 7 million tons higher than the corresponding 1991 figure given by the Agricultural Academy of China (1995:95). In counties where animal husbandry plays a key role, the manure of large animals may dominate in total organic fertilizer, and animal manure is often used as fuel rather than as plant nutrient. Hence, to avoid unrealistically high estimates of organic fertilizer application in these counties, we impose a ceiling of 120 tons of raw organic fertilizer per worker (Wiemer, 1994), which is equivalent to about 1.2 tons of nutrient content.

For farmland, we use the county-level data on total cultivated land areas and irrigated land compiled by the SLA. The national total of cultivated land areas obtained by summation over counties is some 135 million ha. This figure is about 40 million ha higher than the corresponding national figure published in the *Statistical Yearbook of China* (SSB, 1991:314), but is quite consistent with the figure recently compiled by the SLA based on a detailed land survey (see Fischer *et al*., 1998).[2] In addition to statistical data, the LUC Project database includes several digital layers for China, including climate, land use, vegetation, altitude, and soils. These maps were compiled, reorganized, and edited jointly with LUC's Chinese collaborators to provide a basis for biophysical assessments of surface hydrology and vegetation distribution, and for estimating potential yields of major crops.[3] Although these maps provide useful spatial information for land-use research, their scale is insufficient to derive accurate overlays of the actual farmland in 1990 with soil and terrain resources for differentiating land quality types among actual farmland. Hence, the land quality types (index s) applied at the county level currently only distinguish irrigated and rain-fed land.

In actual farming practice, the distinction between irrigated and rain-fed land is not as strict as is suggested by the statistical figures. In some areas, when adequate rainfall occurs in time for cropping, irrigation is not necessary and the differentiation between irrigated and rain-fed land becomes unimportant. Conversely, when water shortage is severe, irrigation may be impossible despite existing irrigation facilities.

4.3 Potential Yield

Biophysical reality enters the input–output relationships through a potential output index $N(A, \overline{y}(x))$ [see Equation (3.7)] and the cropping system zone index Z_l [see Equation (3.12)], and involves the estimation of potential production $\overline{Y}_{l,s}(x)$ by county and land-use type.

After conducting a detailed AEZ assessment across counties in China, land suitability and potential yields were estimated for 27 major crops, differentiated into some 150 crop types. This evaluation was carried out both for irrigated and rain-fed conditions using the methodology described by Fischer *et al*. (2002). Next, to arrive at the potential yields to be used in the production function [Equation (3.5)], a suitable aggregation had to be performed. This was done in three steps:

- Classification of each 5×5 km grid cell of the LUC land resources inventory for China into one of seven major multiple-cropping zones.

- Classification of cereal crop types into eight crop groups according to crop cycle length and thermal crop requirements.
- Aggregation of results at 5$\times$5 km grid cells to county administrative units.

The calculations and aggregations were performed separately for both rain-fed and irrigated conditions. As an example, the multiple-cropping zones applicable under irrigated conditions are shown in *Plate 1*.

In Zone 1, thermal conditions allow for only one crop to be grown per year. The potential yields are determined by the highest simulated yield among all suitable cereal crop types under irrigated and rain-fed conditions. In Zone 2, temperature profiles permit cultivation of two short-cycle crops or relay cropping systems. Examples are wheat and millet grown in sequence, and wheat and maize relay crops. Yields are calculated separately for crops adapted to cool and to moderately warm or warm conditions. Potential yields at the county level are constructed from these pools according to the observed multi-cropping index (MCI). Zone 3 is a typical double-cropping zone, with wheat or barley grown as a winter crop (including a dormancy period) and crops such as maize, soybeans, or sweet potatoes grown in the warm season. Potential annual yields are constructed from these two pools.

Zone 4 has double cropping similar to Zone 3, except that the main summer crop is one that demands more heat, such as rice or cotton. The majority of Zone 5 is located south of the Yangtze River and permits limited triple cropping consisting of two rice crops and, for instance, green manure. The annual temperature profile is usually insufficient for growing three full crops. When the observed MCI does not exceed 2.0, the combination of the best suitable crops during the cooler and warmer seasons of the year defines the potential annual yield. The more the observed MCI exceeds 2.0, the less applicable are crop types with long growth cycles because of the time limitations. When the MCI approaches 3.0, only crop types requiring 120 days or fewer are considered when calculating annual output. Zone 6 covers southern China and allows three crops to be grown sequentially. A typical example is the cropping system with one crop of winter wheat and two rice crops grown between spring and autumn. In this case, only short cycle crops can be considered.

Finally, Zone 7, in the southern-most part of China where tropical conditions prevail, allows three crops that are well adapted to warm conditions (e.g., rice) to be grown. In our calculation, this condition is satisfied when the growing season is year-round and annual accumulated temperature (above 10^{o}C) exceeds 7,000 degree-days. Only crop types requiring fewer than 120 days until harvest are considered when the MCI exceeds 3.0.

Table 4.1 shows the number of counties in each cropping system zone under irrigated conditions used in the estimation. Where there were only a very few counties in a cropping system zone of a particular region, the observations were

Table 4.1. Number of counties per cropping system zone used in estimation, by region.

Cropping system zone	Region: North	Northeast	East	Central	South	Southwest	Northwest/ Plateau
(1) Single cropping	94	138				62	200
(2) Limited double	111	21		10		64	48
(3) Double cropping	287		73	14		102	22
(4) Double with rice			115	171	18	90	
(5) Double rice			41	62	39	66	
(6) Triple cropping					116		
(7) Triple rice					78		
Total	492	159	229	257	251	384	270

added to those of the adjacent zone. *Plate 2* summarizes the results of the biophysical assessment weighted by actual shares of irrigated and rain-fed cultivated land in each county.

4.4 Crop Mix

Not all of the 16 crops considered are grown in all counties or even in all regions. To capture this phenomenon, scaling parameters were introduced into the crop-mix index function [Equation (3.4)]. *Table 4.2* gives the shares of each crop in total revenue and the number of counties where the crop is grown. The patterns clearly differ across regions. Rice, maize, and wheat contribute most to revenue. However, fruit and vegetables are also important products in most regions.

Table 4.2 does not capture the broad variation of over 400 crop combinations which enter the model through the crop-mix variables M_m. These variables are defined in *Table 4.3*. The guiding principles in the definition of crop-mix variables were not to exceed a total of four crop-mix parameters and to give missing major crops priority over the less important ones. Each county has at most one nonzero crop-mix dummy. *Table 4.4* presents the results of these crop-mix definitions.

4.5 Data Checking

Multiple checks were conducted to improve data reliability and consistency. Various relative indicators were checked, such as the irrigation ratio, land per laborer, land per capita, output per sown hectare, and non-land inputs per hectare and per laborer. Occasionally, errors in the original publications could be corrected by comparing different data sources. In some cases, missing or dubious data could be

Table 4.2. Share of crop in total revenue (%) and number of counties where crop is grown.

	Region													
	North		Northeast		East		Central		South		Southwest		Northwest/Plateau	
Crop	%	Obs	%	Obs	%	Obs	%	Obs	%	Obs	%	Obs	%	Obs
Rice	32.0	467	6.7	116	14.4	227	4.5	219	0.9	155	9.5	380	36.2	268
Wheat	3.2	244	18.5	154	45.3	226	62.4	257	48.3	250	36.3	360	4.7	101
Maize	18.4	485	35.5	159	3.9	194	1.5	235	1.6	238	13.1	376	16.8	231
Sorghum	0.9	471	4.4	145	0.1	76		182		109	0.6	277	1.3	156
Millet	1.8	468	1.0	154		18		57		79		65	1.8	186
Other starchy crops	1.3	492	0.7	158	3.3	228	0.7	256	0.3	231	2.6	381	5.6	266
Root crops	2.2	492	1.4	145	1.4	216	1.0	256	1.9	250	3.1	379	2.4	250
Soybeans	2.9	492	11.7	158	3.0	223	1.8	256	1.5	246	1.4	371	4.1	197
Oilseeds	6.2	490	2.5	156	6.4	228	5.4	257	4.2	251	6.4	373	8.6	270
Cotton	13.8	385	0.2	21	7.2	184	7.1	198	0.1	34	1.6	97	2.1	45
Sugarcane		136	1.6	106	0.2	188	0.6	234	7.4	249	1.7	296	1.9	132
Fibers	0.3	265	2.3	120	0.8	190	0.8	234	0.1	157	0.4	295		91
Tobacco	1.6	272	1.7	136	0.3	96	1.4	209	1.6	192	4.5	362	1.4	150
Tea		33			1.4	148	1.2	233	1.3	207	1.3	303		20
Fruit	8.2	490	3.3	141	3.1	229	2.8	245	12.7	248	4.0	383	5.7	253
Vegetables	7.0	491	8.4	158	9.0	229	8.9	257	18.0	250	13.5	374	7.2	262
Total number of counties		492		159		229		257		251		384		270

Note: Obs = number of observations.

Table 4.3. Definition of crop-mix variables M_m.

Region	Mix 1	Mix 2	Mix 3	Mix 4
North	Wheat	Maize/cotton/fruit	$\geq$ 3 smaller crops	–
Northeast	Maize/rice/soybeans/ vegetables	Wheat	$\geq$ 3 smaller crops	–
East	Rice or wheat	$\geq$ 5 smaller crops	–	–
Central	Rice/vegetables/cotton	$\geq$ 3 smaller crops	–	–
South	Rice/vegetables/fruit/ sugarcane	$\geq$ 3 smaller crops	–	–
Southwest	1 of rice/vegetables/ maize/wheat	2 or 3 of wheat/rice/ vegetables/maize	–	–
Northwest/Plateau	1 of wheat/maize/ fruit/vegetables	2 or 3 of wheat/maize/ fruit/vegetables	4 or 5 smaller crops	$\geq$ 6 smaller crops

Note: Crop-mix variables M_m, m = 1,...,4, are used to indicate the absence of one or more crops in a county. For instance, if wheat is not present in the crop mix of a county l in the Northeast region, then crop-mix variable M_{l2} is set to one.

Table 4.4. Number of counties corresponding to the crop-mix variables, by region.

	Region						
Variable	North	Northeast	East	Central	South	Southwest	Northwest/Plateau
Other mix	130	88	200	159	123	163	87
Mix 1	25	7	5	59	7	14	36
Mix 2	87	42	25	39	121	13	8
Mix 3	250	22				194	101
Mix 4							38
Total	492	159	229	257	251	384	270

Table 4.5. Number of observations per region.

	Region							
	North	Northeast	East	Central	South	Southwest	Northwest/ Plateau	Total
All counties	510	184	244	275	272	402	491	2,378
Missing data	13	25	15	18	21	18	212	322
Outliers (labor/ machinery)	5	0	0	0	0	0	9	14
Total used for estimation	492	159	229	257	251	384	270	2,042

corrected by reference to data for other years. When data for a given county were missing or appeared to be highly implausible but could not be corrected by using data from other sources, that county was dropped from the estimation.

Of the 2,378 administrative units contained in the LUC database in total, 2,042 counties were retained in the study; in other words, the data for these counties were complete and were judged sufficiently reliable to be used for both the output and input sides of the estimation. *Table 4.5* gives an account by region. Incomplete county-level records eliminated 322 counties; outliers, mainly for labor and machinery figures, eliminated another 14 (see also Section 4.2). These outliers were concentrated in the North and Northwest/Plateau regions. Only 20 counties on the Plateau located in the Qinghai province qualified for inclusion in the estimation. Xizang (Tibet) had no acceptable data records at all. Consequently, it was decided to pool Qinghai with the Northwest region based on the similarity of the cropping zone patterns.

Notes

[1] We initially used the total number of large animals as a proxy for draft animals. However, because of its poor performance in all estimations, we ultimately had to drop this proxy from the estimation.

[2] Personal communications with Chinese officials suggest that the farmland data compiled by the SLA based on detailed surveys will eventually replace the unrealistic estimates published in the *Statistical Yearbook of China*. Except where specifically mentioned, the data in this subsection are derived from various publications of China's National Bureau of Statistics.

[3] For detailed documentation and references regarding the compilation and editing of these land-use and soil maps, see http://www.iiasa.ac.at/Research/LUC/.

5

Estimation Results

Parameters of the model described in Section 3 were estimated by nonlinear least squares (NLS) for each region separately, except for the Northwest and Plateau regions (i.e., a few counties in Qinghai province), which were treated jointly because the number of valid observations for the Plateau region (some 20) was too low for it to be estimated separately. Results are presented as follows. In Section 5.1, we check whether the error term meets the statistical requirements, thus allowing NLS to be considered as a maximum likelihood estimator. In Section 5.2, we discuss the estimation results of the input response function G. Coefficient values of the output index Q are reported in Section 5.3. Finally, we present and discuss the spatial distribution of calculated implicit prices in Section 5.4, and the marginal productivity of input factors in Section 5.5.

5.1 Analysis of Error Term

To test whether NLS amounts to maximum likelihood estimation, we check normality, homoscedasticity, and independence of the error term. We apply two tests, one parametric and one nonparametric. First, we use the common Shapiro–Wilk test (Shapiro and Wilk, 1965) to check whether for the sample as a whole the errors are a random sample from the normal distribution. Second, we check whether errors might be spatially correlated, albeit locally. This is done by applying a spatial nonparametric (kernel density) regression (Bierens, 1987; Keyzer and Sonneveld, 1997) regressing the error term on the longitude and latitude of the counties. For each county, the estimated value is calculated and the derivative with respect to longitude and latitude and the estimated probability of a wrong sign for that derivative are calculated. Lack of spatial correlation is signalled by frequently changing signs of derivatives and a high average probability of a wrong sign of error for a given derivative.

Table 5.1 presents the Shapiro–Wilk statistic. The normality test is passed at the 5% level for all regions. The table also shows results from kernel density regression and indicates that no spatial dependency could be detected anywhere. On average, the probability of a wrong sign of the derivative in either direction is close to 0.5, implying that the error term could vary in either direction. Therefore, there is no

Table 5.1. Tests on the error term.

	Region						
Coefficient	North	Northeast	East	Central	South	Southwest	Northwest/ Plateau
Shapiro–Wilk's W	.989	.977	.986	.982	.980	.988	.983
Probability $< W$	.876	.231	.726	.416	.234	.820	.453
	Spatial dependency using the mollifier method						
Probability of wrong sign of derivative:							
Longitude	.454	.443	.454	.461	.458	.465	.446
Latitude	.441	.418	.455	.457	.452	.448	.423

need to correct for spatial correlation of errors in the regression, and homoscedasticity and independence can be assumed.

We conclude that the model can be estimated by least squares (LS). Appendix A describes an iterative numerical procedure to perform this estimation.

5.2 Input Response

The coefficient values, their likelihood ratios, and the elasticities of the input response equations were actually estimated simultaneously using the output mix equations. The likelihood ratio is used to check the robustness of the coefficients.

First, let us briefly recapitulate its main principles (see Gallant, 1987; Davidson and MacKinnon, 1993). We denote model parameters by ζ_1, ζ_2. Under our null hypothesis H_0, $\zeta_1 = \overline{\zeta}_1$ and ζ_2 is unrestricted, while under the alternative hypotheis H_1, both ζ_1 and ζ_2 are unrestricted. With maximum likelihood estimation, the significance level of an estimated parameter $\hat{\zeta}_1$ can be determined by an F-test: $F(j,\, n{-}m) = \left(\frac{S(\overline{\zeta}_1,\tilde{\zeta}_2)}{S(\hat{\zeta}_1,\hat{\zeta}_2)} - 1\right) \cdot \frac{n-m}{j}$, where n, m, and j are the number of observations, parameters, and restrictions, respectively; $S(\hat{\zeta}_1, \hat{\zeta}_2)$ is the minimum residual sum of squares corresponding to maximization of the unrestricted likelihood function; and $S(\overline{\zeta}_1, \tilde{\zeta}_2)$ is the residual sum of squares for given reference value $\overline{\zeta}_1$ and free $\tilde{\zeta}_2$, corresponding to maximization of the restricted likelihood function. The critical value for the region with smallest sample size (i.e., the Northeast region), F(1,159) at 0.95, is 3.83.

As a reference value we use 50% of the original estimate $\hat{\zeta}_1$, as opposed to the usual reference value zero, because the function form is given and all variables eventually must enter the welfare model.[1] Hence, we need to assess the robustness of the estimated parameter value, rather than decide whether the variable should be included at all.

Coefficients

Table 5.2 presents the estimated coefficients of the input response function index G, their corresponding likelihood ratios, and the number of observations in each region. Clearly, no likelihood ratio can be calculated for parameters with zero value. Since $\sum_j \theta_j = 1$ for $\theta_{\mathrm{Nutrient}}$, no likelihood ratio is estimated. As the parameter $\delta_{\mathrm{Rainfed}}$ is by definition equal to unity, it has no likelihood ratio value.

As described in Section 3.3, the area index $H(A)$ is preset before estimation. The parameter $\delta_{\mathrm{Irrigated}}$ converts irrigated land into rain-fed equivalent. It is chosen in the interval between unity, and the selection of the final value is based on the assessment of the significance level (see note [1]). The estimation results for the Northeast region generally deviate on the input side. This result is probably caused by the low quality of the input data and the estimated potential production in this region. All parameters are significant at the 95% level except for $\beta_{\mathrm{Nutrient}}$ in the Northeast region.

Not surprisingly, the input-specific parameters γ show a large range of variability across regions, justifying estimation by region as opposed to a pooled estimation for China as a whole. Generally, the constants β of the input groups are small or zero. The upper bound for ρ_{Power} of –.25 is in effect for five regions. The substitution elasticities for the power-related inputs range from 0.38 in the Southwest region to 0.80 in most other regions. Perfect substitution between chemical and organic fertilizer is suggested for the four southern regions.

Elasticities and marginal values

As a further description of the estimation results, in *Table 5.3* we present the output elasticities by input category, evaluated at the regional mean (see Appendix B for the analytical forms of these elasticities). Since the input response function G assumes constant returns to scale, the input elasticities add up to unity.

The results suggest a differentiation into three zones. The first is the southeastern part of China, comprising the East, Central, South, and to some extent Southwest regions. These regions show a great similarity in elasticities for most inputs and input groups (power, nutrient, and land). The elasticity is highest for chemical fertilizer, followed by machinery and irrigated land; labor has a smaller contribution to the output index. The second zone comprises the North and Northwest/Plateau regions, where the similarity between the elasticities is mainly in the pattern rather than the levels with respect to non-land inputs. The levels of elasticities in the North region are comparable with those in the first zone. The picture is different in the remaining Northeast region, which has the highest elasticity for labor.

Table 5.2. Estimated coefficients for the input response function.

	Region						
Coefficient	North	Northeast	East	Central	South	Southwest	Northwest/ Plateau
$\zeta_{\text{Single cropping}}$	0.939	182.131	–	–	–	3.050	40.205
	33.8	*136.6*				*258.0*	*129.3*
$\zeta_{\text{Limited double}}$	0.892	169.202	–	5.150	–	2.217	32.751
	41.8	*75.0*		*92.5*		*208.2*	*151.3*
$\zeta_{\text{Double cropping}}$	0.841	–	5.983	4.353	–	2.111	33.862
	43.6		*711.4*	*159.9*		*275.5*	*154.9*
$\zeta_{\text{Double with rice}}$	–	–	5.768	3.502	2.806	1.891	–
			793.6	*595.0*	*111.8*	*32.8*	
$\zeta_{\text{Double rice}}$	–	–	5.169	2.887	2.553	1.742	–
			636.0	*2,077.7*	*178.8*	*62.9*	
$\zeta_{\text{Triple cropping}}$	–	–	–	–	2.365	–	–
					30.5		
$\zeta_{\text{Triple rice}}$	–	–	–	–	2.595	–	–
					78.7		
θ_{Power}	0.320	0.700*	0.430	0.365	0.341	0.300*	0.555
	376.6	*772.9*	*4.8*	*115.4*	*160.2*	*210.7*	*22.7*
θ_{Nutrient}	0.680	0.300	0.570	0.635	0.659	0.700	0.445
β_{Power}	0.000	0.000	0.013	0.001	0.005	0.006	0.001
			20.8	*68.7*	*122.7*	*33.9*	*16.8*
β_{Nutrient}	0.000	0.031	0.005	0.000	0.000	0.013	0.003
		2.8	*96.6*			*15.4*	*10.6*
ρ_{Power}	–0.250*	–0.250*	–0.250*	–0.250*	–0.250*	–1.630	–1.265
	43.4	*126.1*	*15.5*	*20.4*	*24.1*	*74.6*	*48.9*
ρ_{Nutrient}	0.700*	0.700*	1.000*	1.000*	1.000*	1.000*	0.700*
	30.8	*17,773.5*	*16.8*	*3,552.1*	*243.1*	*255.3*	*3.2*
γ_{Labor}	0.161	2.062	0.464	0.389	0.291	3.010	7.856
	30.0	*14.5*	*15.7*	*50.2*	*40.9*	*22.5*	*16.6*
γ_{Machine}	0.807	2.141	1.024	1.779	1.457	3.179	23.589
	446.5	*12.1*	*153.5*	*2,264.7*	*817.3*	*34.9*	*22.6*
$\gamma_{\text{Chemicals}}$	3.235	0.337	0.160	1.578	0.728	0.934	0.120
	38.0	*10.8*	*549.5*	*826.3*	*174.4*	*12.8*	*12.5*
γ_{Organic}	1.481	0.025	0.135	0.770	0.623	0.387	0.029
	37.8	*11.2*	*97.3*	*75.5*	*28.3*	*37.8*	*13.8*
$\delta_{\text{Irrigated}}{}^{\dagger}$	2.110	1.590	1.000	1.000	1.000	1.000	2.210
	35.5	*4.9*	*117.2*	*54.4*	*28.7*	*30.6*	*22.2*
$\delta_{\text{Rainfed}}{}^{\dagger}$	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Observations	492	159	229	257	173	384	270

*Parameter at bound.
† Preset value.
Note: Figures in italics represent likelihood ratios.

Table 5.3. Output elasticities of land and non-land inputs at the regional mean.

	Region						
Input	North	Northeast	East	Central	South	Southwest	Northwest/ Plateau
Labor	0.052	0.172	0.095	0.054	0.036	0.028	0.100
Machinery	0.248	0.160	0.216	0.279	0.202	0.211	0.331
Power	0.300	0.332	0.311	0.333	0.238	0.239	0.431
Chemical fertilizer	0.309	0.122	0.392	0.344	0.376	0.398	0.209
Organic fertilizer	0.084	0.005	0.121	0.102	0.184	0.192	0.042
Nutrient	0.393	0.127	0.513	0.446	0.560	0.590	0.251
Irrigated area	0.215	0.140	0.131	0.165	0.127	0.063	0.138
Rain-fed area	0.092	0.401	0.045	0.056	0.075	0.108	0.180
Land	0.307	0.541	0.176	0.221	0.202	0.171	0.318
Elasticity of land-index H if change is attributed to:							
Irrigated area	0.414	0.779	0.185	0.221	0.203	0.171	0.544
Rain-fed area	0.196	0.490	0.185	0.221	0.203	0.171	0.246

The elasticities of land-use types might convey the wrong impression that investment in irrigation in the Northeast, Southwest, and Northwest/Plateau regions is not profitable. In fact, the lower elasticities for irrigated land in some regions merely reflect the lower area under irrigation [see Appendix B, Equation (B.2)]. For example, in the Northeast region rain-fed agriculture is the dominant land-use type (78%) and $\delta_{\mathrm{Irrigated}}$ is 1.59, resulting in a ratio of rain-fed to irrigated land of about 2.9. To assess the relative productivity of investment in irrigated and rain-fed land, a common area basis is needed. The two rows at the bottom of *Table 5.3* measure the percentage increase in output if the land basis of irrigated and rain-fed land expands by 1% in each case. Since $\delta_{\mathrm{Irrigated}}$ exceeds $\delta_{\mathrm{Rainfed}}$, irrigation appears to be more productive.

As a further characterization of the differences across regions, we calculate the marginal values (see *Table 5.4*). These reflect the variability of implicit wages, rental cost of land and machinery, and price of chemical and organic fertilizers. The marginal value of labor is high in the northern regions and, as could be expected, low in the densely populated areas of the central and southern regions, where marginal returns to land are relatively high for both irrigated and rain-fed land. Despite its dense population, the eastern region has a relatively high marginal value of labor, reflecting the attractiveness of the more industrialized area.

5.3 Output Index

The coefficients of the output index function Q appear in *Table 5.5*. For the major staple crops (rice, wheat, and maize), they are generally similar across regions.

Table 5.4. Marginal values at the regional mean (yuan).

	Region						
Derivative	North	Northeast	East	Central	South	Southwest	Northwest/Plateau
$\partial G(V,A)/\partial V$							
Labor (persons)	113.90	580.05	242.11	125.62	88.83	41.63	160.20
Machinery (kW)	429.76	348.17	614.77	1,086.19	784.91	1,056.26	573.56
Chemical fertilizer (kg)	4.72	1.61	5.76	6.20	5.62	8.23	2.96
Organic fertilizer (kg)	2.70	0.16	4.83	3.03	4.81	3.41	0.77
$\partial G(V,A)/\partial A$							
Irrigated farmland (ha)	1,329.98	1,190.84	862.63	1,296.18	871.70	490.13	539.93
Rain-fed farmland (ha)	630.32	748.95	862.63	1,296.18	871.70	490.13	244.31

Table 5.5. Estimated coefficients for the output function.

	Region						
Coefficient	North	Northeast	East	Central	South	Southwest	Northwest/ Plateau
α_0 †	1.500	1.500	1.500	1.500	1.500	1.500	1.500
	46.6	*25.4*	*29.9*	*35.6*	*35.1*	*74.4*	*42.7*
α_{Rice}	0.780	0.727	0.892	0.752	0.712	0.839	0.890
	36.4	*1.3*	*199.8*	*281.8*	*111.4*	*93.2*	*18.3*
α_{Wheat}	1.171	0.881	1.099	1.374	5.425	1.035	1.024
	163.7	*5.0*	*21.0*	*32.3*	*33.1*	*28.5*	*17.0*
α_{Maize}	1.433	0.668	3.863	10.922	13.532	0.030*	0.030*
	38.4	*11.1*	*14.5*	*23.5*	*23.0*	*31.9*	*16.5*
α_{Sorghum}	2.095	0.168	0.030*	0.030*	49.332	0.030*	0.793
	43.7	*5.0*	*14.5*	*17.3*	*20.5*	*30.3*	*16.9*
α_{Millet}	0.720	0.586	0.934	0.806	2.346	1.205	0.672
	48.7	*9.4*	*16.0*	*17.7*	*39.6*	*68.5*	*19.7*
$\alpha_{\text{Other starchy}}$	0.944	3.588	0.714	2.592	0.030*	0.592	0.159
	30.9	*6.9*	*14.2*	*16.5*	*18.8*	*33.3*	*17.6*
$\alpha_{\text{Rootcrops}}$	0.383	0.030*	0.534	0.724	0.030*	0.841	0.959
	30.2	*5.9*	*14.7*	*16.5*	*19.9*	*33.1*	*16.2*
α_{Soybean}	2.624	1.231	3.467	6.385	0.030*	0.030*	0.030*
	33.7	*3.9*	*15.3*	*17.8*	*20.1*	*30.0*	*16.9*
α_{Oilseed}	1.324	0.503	3.300	4.417	7.972	2.361	0.526
	28.2	*5.4*	*17.7*	*23.9*	*31.3*	*29.1*	*17.0*
α_{Cotton}	6.796	35.730	10.066	9.360	6.079	18.836	11.477
	46.8	*5.5*	*17.6*	*22.0*	*22.7*	*33.3*	*22.0*
$\alpha_{\text{Sugarcane}}$	1.043	0.030*	0.536	0.342	0.201	0.212	0.563
	35.9	*5.0*	*14.7*	*15.8*	*24.1*	*49.6*	*20.7*
α_{Fiber}	4.802	0.030*	2.889	2.577	13.924	11.246	39.267
	34.6	*5.0*	*13.7*	*15.3*	*21.8*	*24.2*	*16.3*
α_{Tobacco}	3.203	8.088	0.030*	7.062	6.844	4.713	1.391
	31.5	*7.3*	*14.3*	*32.8*	*23.4*	*45.5*	*18.3*
α_{Tea}	31.912	–	10.469	12.199	17.698	11.082	0.030*
	32.8		*17.7*	*17.0*	*24.6*	*31.7*	*17.2*
α_{Fruit}	1.674	1.241	1.427	2.504	1.901	2.206	1.885
	30.1	*7.3*	*15.3*	*24.1*	*21.5*	*28.9*	*15.3*
$\alpha_{\text{Vegetables}}$	0.346	0.267	0.364	0.484	0.347	0.461	0.335
	42.1	*7.9*	*26.9*	*29.9*	*18.9*	*64.2*	*19.4*
$\mu_{\text{Mix 1}}$	–0.182	–0.182	–0.076	–0.014	0.121	–0.215	–0.376
	41.6	*7.7*	*12.5*	*14.1*	*20.8*	*35.1*	*34.4*
$\mu_{\text{Mix 2}}$	–0.083	0.203	–0.119	–0.043	0.054	–0.031	–0.022
	41.8	*10.9*	*29.8*	*20.8*	*24.0*	*30.7*	*16.6*
$\mu_{\text{Mix 3}}$	–0.014	0.021	–	–	–	–0.034	–0.043
	32.3	*5.0*				*35.7*	*21.3*
$\mu_{\text{Mix 4}}$	–	–	–	–	–	–	0.019
							17.6

*Parameter at bound.
† Preset value.
Note: Figures in italics represent likelihood ratios.

Deviations are mainly due to the fact that certain crops are sometimes a major crop in one region and a minor crop in another. Wheat and maize are outliers in the South region, where they contribute less than 1% and 1.6% to total crop revenue, respectively. Wheat can only be grown in a few scattered areas in Fujian and Guangdong provinces. The variation in estimates is most pronounced for the minor crops, but estimates are stable for vegetables and to a lesser extent fruits, which are present in almost all counties and crop mixes. The crop-mix correction factors μ_m vary across regions and crop mixes. As expected, most are negative, especially those associated with a major crop. Other crop-mix parameters can be positive, since some crops are minor crops at the regional level, but are major crops at the county level. The significance level for most parameters is well above 95%.

5.4 Implicit Prices

In this section we calculate implicit prices along the lines of profit maximization set out in Section 3.4 and try to compare these with the consumer prices in nearby urban centers and examine their spatial variations. We reiterate that this is a purely hypothetical calculation to give a first impression of the degree to which the prevailing conditions would seem to support the hypothesis.

The difference between farm-gate and consumer prices measures an implicit trade and transportation margin. Clearly, this margin should increase with the distance to the main consuming areas. Because data on free-market consumer prices are not available, *Table 5.6* compares state procurement prices and the implicit producer prices at the regional level for rice, wheat, and maize. The producer prices are weighted by county production. In the main producing regions, they fluctuate around the procurement price levels. As mentioned earlier, the state procurement prices are a quantity-weighted mean of quota prices, negotiated prices, and free-market prices. They may tend to lie below marginal productivity and hence below free-market consumer prices.

The hypothesis of price increase toward urban centers is tested for these three major crops and for the price index using a simple regression. To explain demand for crop supply in a given county, we use the population density of the county and the sum of the urban populations weighted by the distance in kilometers between the given county and all other cities and county towns, as presented in Equation (5.1):

$$W_l = \sum_{l'} \frac{\text{Urban Population}_{l'}}{\exp(0.010\ \text{Distance}_{l,l'})} \ . \tag{5.1}$$

The region-specific dummies measure the difference from the default Southwest region. For the crops, the estimation is limited to the main producing counties; that is, where the value share of the crop is above 15%. *Table 5.7* presents

Table 5.6. Comparison of procurement and implicit producer prices for the major crops.

	Rice		Wheat		Maize	
Region	Procurement	Implicit	Procurement	Implicit	Procurement	Implicit
North			0.66	1.00	0.53	0.42
Northeast	0.64	0.52			0.39	0.43
East	0.65	0.75	0.57	0.68	0.56	0.41
Central	0.60	0.59	0.58	0.73		
South	0.62	0.64				
Southwest	0.55	0.59	0.57	0.42	0.55	0.67
Northwest/Plateau	0.71	0.61	0.64	0.84	0.46	0.39

Source: Procurement prices are from SBB (1992); implicit producer prices are calculated based on Equation (3.13) (regional average is weighted with production).

Table 5.7. Estimated coefficients of the price relationship.

	Rice	Wheat	Maize	Price index
Population density	0.010 (2.7)	0.010 (1.9)	0.029 (6.1)	0.035 (7.5)
Weighted urban population	0.048 (5.2)	–0.052 (1.0)	0.083 (1.9)	0.082 (4.7)
Intercept (Southwest)	0.530 (17.8)	0.461 (8.8)	0.524 (11.7)	0.699 (17.8)
North	0.017 (0.8)	0.538 (22.2)	–0.268 (17.3)	0.143 (9.3)
Northeast	0.053 (3.5)	0.290 (8.5)	–0.235 (15.8)	0.204 (10.2)
East	0.159 (15.8)	0.319 (9.9)	–0.202 (6.0)	0.060 (3.2)
Central	–0.009 (1.0)	0.351 (5.6)	–0.345 (10.6)	–0.044 (2.6)
South	0.033 (3.6)	–	0.648 (32.8)	0.090 (5.0)
Northwest/Plateau	0.140 (6.5)	0.399 (19.5)	–0.232 (16.9)	0.304 (18.0)
R^2	0.30	0.59	0.81	0.25
Observations	1,067	564	685	2,046

Note: t-scores given in parentheses.

the results, which do not reject the hypothesis. The local demand measured by the population density is significant for all crops and for the price index. The coefficient of the neighboring urban population for wheat has the wrong sign but is not significant. The explanatory power of the estimations is acceptable.

We can conclude that the spatial changes in the imputed farm-gate prices follow an economically plausible geographical pattern that is largely shaped by demand and supply forces. This suggests that profit maximization with exogenous price margins at the county level provides a reasonable first-order partial approximation to reproduce the main properties of crop farming. But this only is a first-order, cross-sectional investigation. Improving the price linkage relationship is a subject for further research.

Table 5.8. Input costs per hectare (yuan).

	Region						
Input	North	Northeast	East	Central	South	Southwest	Northwest/ Plateau
Chemical fertilizer	1,021	247	1,926	1,801	1,663	994	257
Organic fertilizer	289	9	607	557	841	495	50
Machinery	860	318	1,047	1,481	908	513	369
Wages and land	1,313	1,428	1,367	1,525	1,169	573	524
Total costs	3,483	2,002	4,947	5,364	4,581	2,575	1,200
Laborers per hectare	1.51	0.46	1.95	2.50	1.76	1.92	0.65
Returns from wages and land per laborer	870	3,104	701	610	664	298	806

5.5 Marginal Productivity

Plate 3 and *4* are based on kernel density regression and show geographical patterns of the marginal productivity of labor and machinery, respectively. For reference, *Plate 5* presents the population density in persons per square kilometer. It appears that the marginal productivity of agricultural labor is usually higher in the neighborhood of large urban areas: Hong Kong, Shanghai, Beijing, Tiajin, and the delta of Liaoning. The figures also show that in the inland southern regions (the Southwest and Central regions) the marginal productivity for machinery is higher and that for labor is lower than in the other regions.

Plate 6 shows the marginal productivity of irrigated land, which stands in fixed, region-specific proportion to the marginal productivity of rain-fed land. The proportion follows the pattern of population density quite closely along the coastal zone and in the Northeast region, but inland the relationship is loose. Although marginal productivity is somewhat higher in the Red Basin area in Sichuan than in the surrounding mountainous area, it is substantially below marginal productivity in comparable urban areas along the coast.

A regional comparison of costs per hectare (see *Table 5.8*) reveals a north-to-south pattern. While implicit costs for labor and land are the dominant inputs in the northern regions, chemical fertilizer is the dominant input in the southern regions. The difference in cropping patterns explains part of this difference. For example, the Northeast region has single cropping, with limited double cropping only in Liaoning; in contrast, the southern regions have up to triple rice cropping, with higher fertilizer requirements.

The average implicit returns for land and wages per laborer are the lowest in the Southwest region. In 1990, an average laborer earned an annual income of 298 yuan. For the coastal South, East, and North regions the earnings for a crop laborer range from 664 yuan to 870 yuan on average. This pattern is in line with the observed out-migration to the coastal provinces during the past decade.

Note

[1] The alternative values against which the estimated values are tested are as follows: $\theta_{\text{Power}} = .5, \zeta_z = 1, \mu_m = 0, \rho_{\text{Power}} = -1.5, \rho_{\text{Nutrient}} = .7$ or 1, and $\alpha_0 = 2$. For $\delta_{\text{Irrigated}} = 1$, the ratio of the potential yield on irrigated land to the potential yield on rain-fed land is used as the alternative, in the other cases whether or not $\delta_{\text{Irrigated}} = 1$ is the hypothesis. These alternatives stand at $\delta_{\text{Irrigated}} = 1.00$ for the North region, 1.00 for Northeast, 1.05 for East, 1.04 for Central, 1.03 for South, 1.16 for Southwest, and 1.00 for Northwest/Plateau.

6

Summary and Conclusions

This report highlights the specification and cross-sectional estimation of a spatially explicit transformation function for crop production in China based on county-level data for 1990. In addition to inputs such as labor, machinery, and chemical fertilizer, we include organic fertilizer. Biophysical conditions for crop production vary substantially in China. Potential production ranges from single cropping of maize with less than 4 tons per hectare in the northern provinces to triple rice cropping with 18 tons per hectare or more along the coast in the south. The production relationship explicitly takes these potentials into account and employs them as an asymptote to actual yields in the specification. The usual approach of profit maximizing subject to a production function could not be adopted because no county-specific price information is available and because profit maximizing is not the appropriate behavioral principle. In 1990, marketing, pricing, and production for the major staples were still largely controlled by government agents. Hence, the seven regional input–output functions were estimated in their primal form.

The estimation results are satisfactory in terms of quality of fit, signs and significance of parameters, homoscedasticity, and lack of spatial correlation of errors. The coefficients are interpretable in that they reflect the regional differences in the crop production systems. The associated elasticities of aggregate output with respect to inputs reflect reasonably well the relative scarcity of irrigated land, labor, and other inputs across the different regions. Marginal productivity of labor is usually higher in the neighborhood of large urban areas, notably those along the coast. This pattern is in line with the observed out-migration to the coastal provinces during the past decade. The marginal productivity of machinery is highest in the Central and Southwest regions, whereas the chemical and organic fertilizers are perfect substitutes in the densely populated regions.

The implicit producer prices calculated as marginal productivity show an economically plausible spatial pattern strongly correlated to distance from the main consuming areas. We have emphasized that this linkage needs further improvement, as it should also consider government regulations.

This production system is a key building block for LUC's intertemporal welfare-maximizing policy analysis model. With this policy analysis model, LUC intends to examine a range of development and policy scenarios for the period from 2001 to 2030 in light of China's commitments with respect to the World Trade Organization (WTO), and to evaluate the policy needs as formulated in the

Agricultural Action Plan for China's Agenda 21. The main issues in this project, executed by Chinese and European institutes and partly sponsored under the European Union's Fifth Framework Programme, include the WTO accession, China's rapidly rising domestic demand for animal products, and sustainable development of China's agricultural sector.

Leaving policy analysis to the principal model, this report focuses on the methodological and technical aspects of the crop production module of the model.

Appendix A:

Description of the Estimation Procedure and Calculation of Partial Derivatives for the Taylor Expansion Approach

The transformation function described in Sections 3.2 and 3.3 can be written in more compact form as follows:

$$Q_l(Y, M; \alpha_0, \alpha, \mu) = C_l G_l(V, A, \overline{y}(x); \theta, \rho, \beta, \gamma, \delta)\,, \tag{A.1}$$

where Greek symbols refer to parameters that should be estimated or fixed. On the output side, Q_l is a combination of a sum of crop-mix constants and a CES:

$$Q_l = \left(1 + \textstyle\sum_m \mu_m M_{lm}\right) \left(\textstyle\sum_c (\alpha_c Y_{lc})^{\alpha_0}\right)^{1/\alpha_0}. \tag{A.2}$$

On the input side, C_l is the sum of cropping zone constants:

$$C_l = \sum_z \zeta_z Z_{lz}\,,$$

while G_l is the generalized Mitscherlich-Baule function:

$$G_l = \textstyle\prod_j f\left(V_l, A_l; \beta, \gamma; \delta, \rho\right)^{\theta_j} N\left(A_l, \overline{y}_l(x); \delta\right), \tag{A.3}$$

with

$$\begin{aligned}
f_{lj} &= 1 - \exp\left(-\beta_j - w(V_l/H_l)\right)\,, \\
w_{lj} &= \left(\sum_{k \in j} \gamma_k (V_{kl}/H_l)^{\rho_j}\right)^{1/\rho_j}\,, \\
H_l &= \sum_s \delta_s A_{ls} \quad \text{, and} \\
N_l &= H_l \overline{y}_l\,.
\end{aligned}$$

Index l stands for counties, m for crop mix, c for crops, z for multiple-cropping zones, s for land-use types, j for input groups, and k for inputs. Estimation is performed for each of seven regions.

Numerical implementation of the estimation procedure

The estimation problem is relatively large and complex, and highly nonlinear and nonconvex in parameters. Thus it cannot be solved by invoking a standard numerical optimization procedure. For this reason, it was necessary to develop an iterative procedure, which operates in five steps:

1. Generation of the initial quantities $\tilde{q}_l = \tilde{Q}_l/H_l$ as data for the separate estimation of the input and output functions. Calculation of $\overline{y}_l = \overline{Y}_l/H_l$.
2. Iterative estimation of parameters of the input function $\tilde{q}_l = C_l \cdot G_l/H_l + \varepsilon_1$ by linear regression using a first-order Taylor expansion of the function, which is adjusted until convergence. This provides good initial estimates for use in Step 3.
3. Further estimation of the parameters of the input function in the original nonlinear form.
4. Estimation of parameters of the output function $\tilde{q}_l = Q_l/H_l + \varepsilon_2$ in the nonlinear form for fixed substitution parameter α_0.
5. Updating of the quantity index $\tilde{q}_l$ and repetition from Step 3 until convergence is reached.

Thus, Steps 1 and 2 constitute the initialization and Steps 3 to 5, the actual estimation. It is worth noting that introducing the quantity index $\tilde{q}_l$ as an anchor significantly improves the performance of the regressions, although it is possible in principle to estimate both output and input functions simultaneously based on a single equation such as Equation (A.1). It should be added that since the estimation problem is non-convex, only a stationary point could be obtained which appears to be a local optimum. The robustness of this estimate was tested by checking convergence to the optimal value after shocks and by assessing the resulting change in the other parameters in the calculation of the likelihood ratios. The likelihood ratios are calculated by iteratively setting parameters at half their originally estimated value.

We conclude with some additional remarks on the various steps:

Step 1. The initial county-level output index $\tilde{Q}_l$ is calculated based on the available provincial prices P_{rc}, the national prices P_c, and the county-level crop outputs Y_{lc}. The provincial crop output Y_{rc} is the sum of the county-level outputs. A provincial output price index P_r^i is calculated as

$$P_r^i = \sum_c P_{rc} Y_{rc} / \sum_c P_c Y_{rc} \tag{A.4}$$

to measure the departure of the provincial price level from the national one. This provincial-level price index, together with provincial-level output prices, is applied to all counties l in province r, yielding a county-level output index $\tilde{Q}_l$:

$$\tilde{Q}_l = \sum_c Y_{lc} P_{rc} / P_r^i \ . \tag{A.5}$$

Step 2. The iterative parameter estimation in this step uses a Taylor expansion of the function of residuals $e\,(z;\psi)$, where z denotes the extended vector of independent variables and ψ the vector of parameters to be estimated ($\psi = (\zeta, \theta, \beta, \rho, \gamma)$). Using the definitions of Equations (A.2) and (A.3), the disturbances $e_l(z;\psi)$ can be written as

$$e_l(z;\psi) = \tilde{q}_l - C_l(Z_{lz};\zeta_z) G(V_{lj}, A_{ls}, \overline{y}_{ls}; \theta_j, \beta_j, \rho_j, \gamma_k)/H_l \ , \tag{A.6}$$

and the derivatives are as follows:

- Partial derivative with respect to ζ_z:

$$\frac{\partial e_l}{\partial \zeta_z} = -Z_{lz} G_l / H_l \tag{A.7a}$$

- Partial derivative with respect to θ_j:

$$\frac{\partial e_l}{\partial \theta_j} = -\log f_{lj} C_l G_l / H_l \tag{A.7b}$$

- Partial derivative with respect to β_j:

$$\frac{\partial e_l}{\partial \beta_j} = -\theta_j \frac{1 - f_{lj}}{f_{lj}} C_l G_l / H_l \tag{A.7c}$$

- Partial derivative with respect to ρ_j:

$$\frac{\partial e_l}{\partial \rho_j} = \frac{-\theta_j w_{lj}}{\rho_j} \frac{1 - f_{lj}}{f_{lj}} \left(\frac{\log w_{lj}^{\rho_j}}{\rho_j} - \frac{\sum\limits_{k \in j} (\gamma_k v_{lk}^{\rho_j} \log v_{lk})}{w_{lj}^{\rho_j}} \right) C_l G_l / H_l \ , \tag{A.7d}$$

with $v_{lk} = V_{lk}/H_l$

- Partial derivative with respect to γ_k , k $\in j$:

$$\frac{\partial e_l}{\partial \gamma_j} = -\theta_j \frac{1 - f_{lj}}{f_{lj}} \frac{1}{\rho_j} w_{lj}^{1-\rho_j} v_{lj}^{\rho_j} C_l G_l / H_l \tag{A.7e}$$

Step 3. To avoid parameters' drifting away during the course of the estimation, parameters ζ, θ, ρ, and η are first estimated, keeping the others fixed, and then parameters β and γ are estimated, keeping ζ, θ, ρ, and η fixed. The parameters are updated until convergence is reached. The updating procedure of the parameters and convergence level are the same as in Step 2.

Step 4. Parameter α_0 is estimated by scanning the interval [1.5, 2].

Step 5. Convergence is reached when two full rounds lead to less than a 0.1% change of the sum of the squares of $\left(\hat{Q}_l/H_l - \hat{C}_l\hat{G}_l/H_l\right)$.

The entire estimation procedure was implemented in GAMS (Brooke *et al.*, 1992).[1] The databases for estimation of the output and input response functions were stored and managed as MS-Excel worksheets. The statistical software package SAS was used to export the basic data into GAMS format, with a proper declaration and initialization of sets in GAMS syntax. The resulting database in GAMS format was stored with the save option "s = ..\data", so that it can be used by the different parts of the GAMS programs independently using the restart option "r = ..\data:".

Note

[1] GAMS stands for general algebraic modeling system. GAMS provides a high-level language for compact representation (and documentation) of large and complex optimization models.

Appendix B:

Output Elasticities of Non-Land Input k and Land Input s, and of Crop c

Output elasticity with respect to non-land input V_{lk}:

$$\frac{\partial G_l}{\partial V_{lk}} \frac{V_{lk}}{G_l} = \frac{1 - f_{lj}}{f_{lj}} \theta_j \gamma_k w_{lj}^{1-\rho_j} \left(\frac{V_{lk}}{H_l} \right)^{\rho_j} \tag{B.1}$$

Output elasticity with respect to land input of type A_{ls}:

$$\frac{\partial G_l}{\partial A_{ls}} \frac{A_{ls}}{G_l} = \frac{\delta_s A_{ls}}{H_l} \left(1 - \sum_j \left(\theta_j \frac{1 - f_{lj}}{f_{lj}} w_{lj} \right) \right) \tag{B.2}$$

Output elasticity with respect to crop Y_{lc}:

$$\frac{\partial Q_l}{\partial Y_{lc}} \frac{Y_{lc}}{Q_l} = \frac{(\alpha_c Y_{lc})^{\alpha_0}}{\sum\limits_c (\alpha_c Y_{lc})^{\alpha_0}} \tag{B.3}$$

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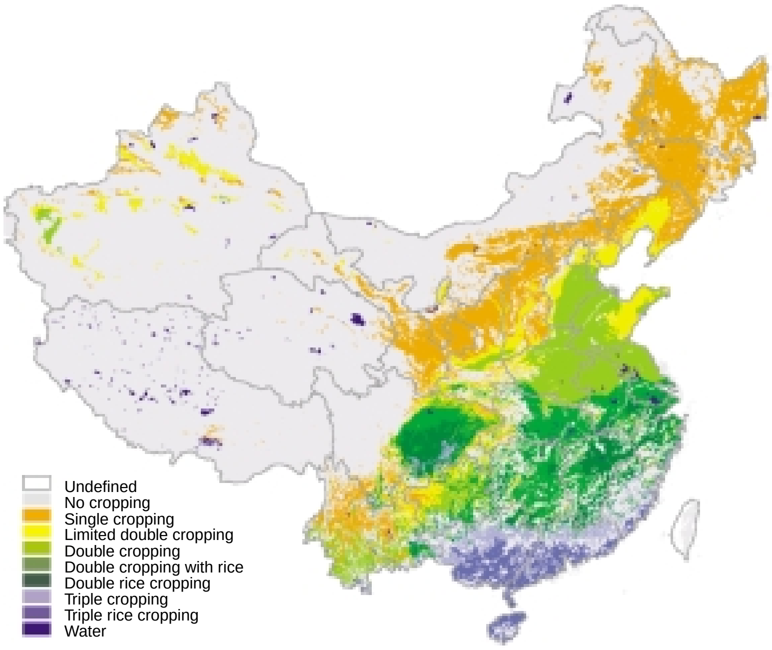

Plate 1. Multiple-cropping zones under irrigated conditions.

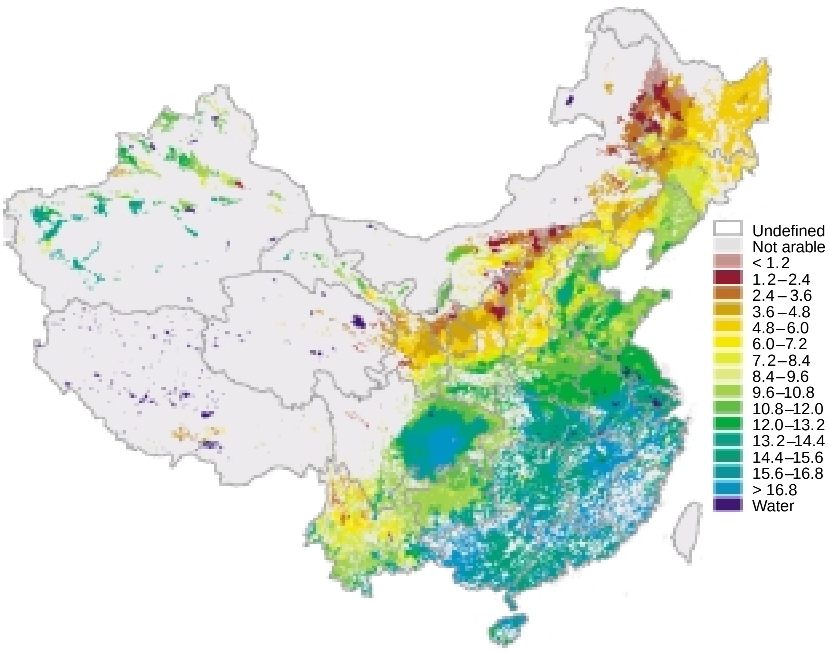

Plate 2. Annual potential production (tons/ha), weighted average of irrigation and rain-fed potentials.

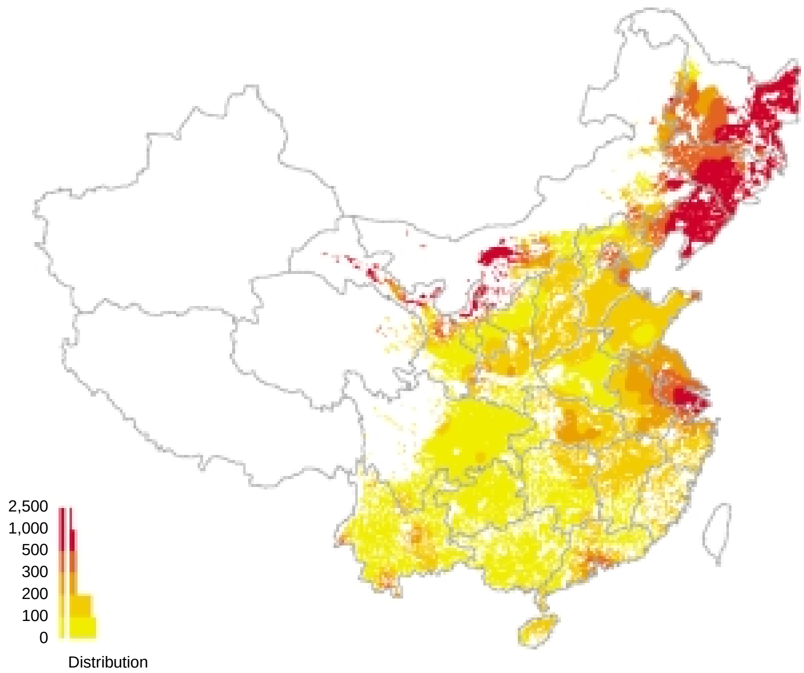

Plate 3. Marginal productivity of labor (yuan/person).

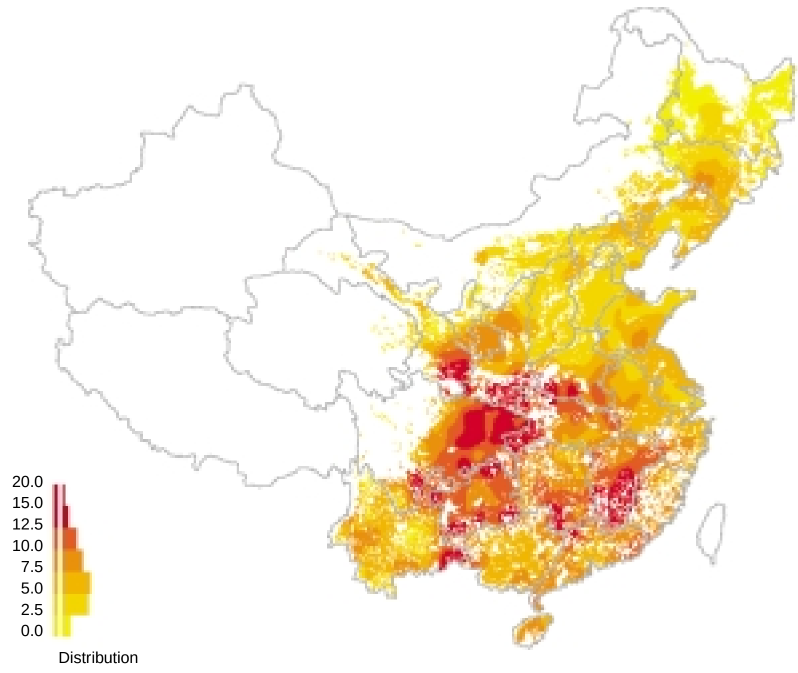

Plate 4. Marginal productivity of machinery (1,000 yuan/10 kW).

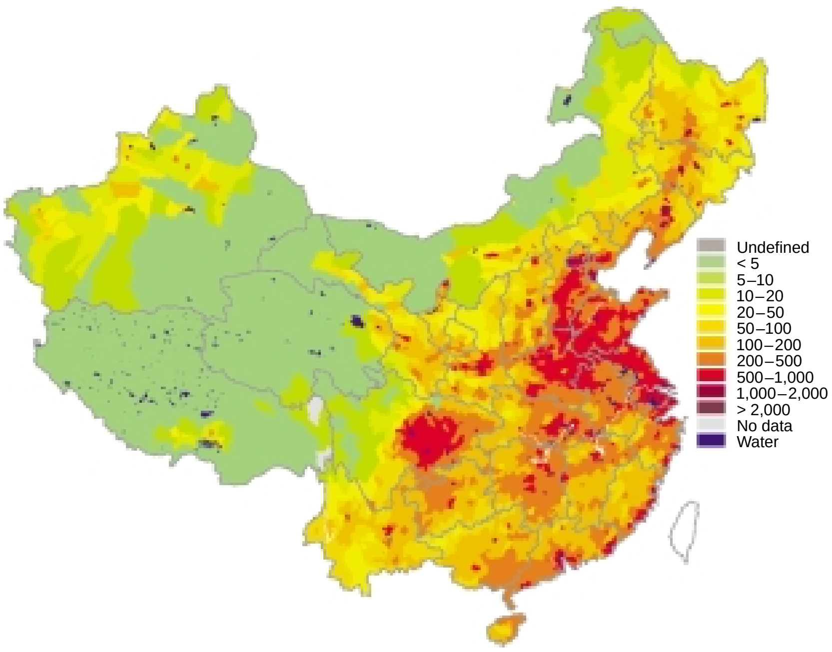

Plate 5. Population density (persons/km^2).

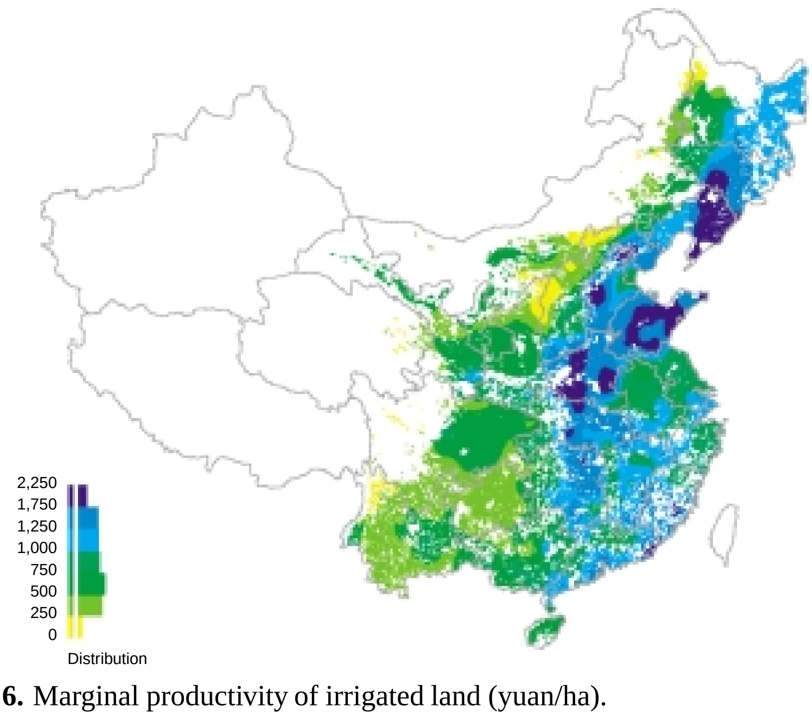

Plate 6. Marginal productivity of irrigated land (yuan/ha).