

**Interim Report**

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# Estimation of agricultural production relations in the LUC Model for China

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## **Abstract**

China's demand for feed-grains has been growing fast during the last two decades, largely due to the increasing meat demand. This raises the important question whether China will in the coming years be able to satisfy these increasing needs which has implications that reach far beyond the country itself, especially in the light of China's upcoming accession to 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 agricultural potentials of the country.

To analyze these issues, the Land Use Change (LUC) Project is engaged in the development of an intertemporal welfare maximizing policy analysis model. The present report presents the input-output relationships for agricultural crops in this 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 2040 counties, on the basis of data for 1990. The inputs are chemical and organic fertilizer, labor and machinery. Irrigated and rain-fed land is distinguished as separate land-use types. Distinct relationships are estimated by cross-section for eight economic regions distinguished in the LUC model. The biophysical potential enters as an asymptote in a generalized Mitscherlich-Baule (MB) 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 reflect rather closely the relative scarcity of irrigated land, labor and other inputs across the different regions. It also appears that if account is taken of the distance to main urban centers, the observed cropping patterns are generally consistent with profit maximization. Confirmation is found for the often noted labor surplus in the Southern and South-Eastern regions.

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# Estimation of agricultural production relations in the LUC Model for China

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## 1. Introduction

Fast economic growth has stimulated China's demand for food and feed-grains. While the country has an impressive record in raising its agricultural production, it is not fully clear to which degree China can or should maintain food self-sufficiency, and whether eventual imports should consist of meat or feed-grains. The answer to these questions is not only important for China itself. It has strong implications for world markets at large. In its *World Food Prospects*, the International Food Policy Research Institute (IFPRI) (Pinstrup-Andersen *et al.*, 1999) anticipates that the net meat export to East-Asia will be 28-fold in 2020, primarily because the demand for meat in China is expected to double. The demand for maize as main feed grain will grow by 2.7 percent per year.

However, the successful economic development has itself created new room for choice and may render any prediction irrelevant that merely extrapolates past trends. Based on this recognition, the IIASA Land Use Change (LUC) Project<sup>2</sup> has opted for an approach that seeks to identify alternative options for agricultural policy through a spatially explicit, intertemporal model. This model accounts for the main biophysical restrictions in the various parts of the country, in conjunction with the main socio-economic factors that drive land-use and land-cover change (Fischer *et al.*, 1996).

The present paper documents the specification of the input-output relationships for crop production and reports the estimation results. These relationships describe, for each of some 2040 counties in China, in the year 1990, the crop output combinations that can,

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<sup>1</sup> All authors provided some specific contributions to the writing of this report. Günther Fischer and Laixiang Sun compiled the database. Günther Fischer developed the agro-ecological assessment model for China and estimated the biophysical potentials. Laixiang Sun and Peter Albersen estimated the input response function. Peter 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 gave technical advice.

under the prevailing environmental conditions (i.e., climate, terrain, soils), be produced from given combinations of chemical and organic fertilizers, labor and traction power, and irrigated and rain-fed land. The relationships are estimated separately for the eight economic regions distinguished in the LUC model<sup>3</sup>. In addition to these input-output relations for crop production, the LUC model contains also components for livestock production, consumer demand, land conversion, and water development. These will be presented in separate reports.

Several examples exist in the literature of agricultural production functions, which were estimated for China. The major interest was generally to assess the level of the total factor productivity and its change, to estimate the marginal productivity and output elasticities of the main production factors, and to evaluate the specific contribution of the rural reform to agricultural growth. On the basis of pooled data at the provincial level Lin (1992) assesses the contributions of decollectivization, price adjustments, and other reforms to China's agricultural growth in the reform period. The study estimates that decollectivization accounted for about half of the output growth during 1978-1984. Wiemer (1994) uses micro-panel data from households and production teams in a rural township to analyze the pattern and change of rural resource allocation before and after the reform. Both studies applied 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 the specific assessment purposes were incorporated into the exponential term of the Cobb-Douglas form.

Two recent studies by Carter and Zhang (1998) and Lindert (1999) incorporate besides the conventional inputs also climate and biophysical information. Carter and Zhang estimate a Cobb-Douglas model for grain productivity for the five major grain-producing regions in China with aridity indices using data over 1980-1990. 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

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<sup>2</sup> IIASA and SOW-VU co-operate in the construction of the LUC model.

<sup>3</sup> The eight LUC economic regions are, respectively: *North* including Beijing, Tianjin, Hebei, Henan, Shandong, and Shanxi; *North-East* 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; *South-West* including Sichuan, Guizhou, and Yunnan; *North-West* including Nei Mongol, Shaanxi, Gansu, Ningxia, and Xinjiang; and *Plateau* representing Tibet and Qinghai.

at county level. In both studies fertilizer input was limited to chemical fertilizer, although the manure aspect is implicitly incorporated in Lindert by an *organic matter* index.

The aim to include the crop input-output relationships within the wider LUC welfare optimum model imposes various requirements. We mention the following:

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 asymptote to actual yields. The building bricks for the potential output calculation are potential yields at county level for different land types (irrigated and rain-fed) 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 the experiences gained in 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.*, 2000). The AEZ assessment is a well-developed environmental approach. It 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 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 uses available information to the maximum. Moreover, it is also directly applicable to assessing 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). This was imposed through respective restrictions on the relevant function parameters.

Third, the estimations must accommodate the limitations of the available information. For instance, no data was available on crop-specific inputs, say, fertilizer applied to wheat. This lack of information is not specific to China but is a fairly common situation 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 to identify derived net output functions separately by commodity (see e.g., Hasenkamp, 1976; Hayami and Ruttan, 1985, among others). These functions use output and input prices and resource levels (land, labor, capital) as dependent variables. However, in the case of China two special difficulties impede the applicability of this approach. First, despite the decollectivization in the 1980s, farm decision-making has not yet fully become a family affair, and various rules and regulations are still in effect which do not find an expression in farm-gate prices and are not formally recorded. The data used in our study refer to the year 1990 when even more decisions were made at village government level than is the case now. Second, the only available output price data are (weighted average) state procurement prices for major crops at provincial and national levels, and there are no published input price data 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.

The paper proceeds as follows. Section 2 describes basic institutional features of the agricultural sector in China during the early 1990s, 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 introduces 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. Some conclusions are provided in Section 6. Two annexes report on the numerical implementation of the estimation procedure and the formulae for elasticity calculations.

## **2. Transformation of the agricultural sector during 1979-1999**

In 1979 China initiated a dramatic reform of the institutional structure in its agricultural sector. From a collective based agriculture, changes were made towards a system in which the individual farm household becomes the basic unit of decision with respect to inputs and most outputs. As a rule, the new family farms are small and fragmented, depend heavily on irrigation, inducing Chinese farmers to save land and capital and to opt for highly labor-intensive practices. The present section reviews the main elements of this transformation process.

### **2.1 Institutional arrangement of China's family farms in the post-reform era**

During the period 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 15-30 years, whereas the village community, via its government, retains other rights associated with the ownership of the land. This land tenure system constitutes a two-tier system with use-rights vested in individual households and the ownership rights in the village community (Dong, 1996; Kung, 1995).

Under the new land tenure system, unlike in the previous collective system, farm households became independent production and accounting units. Each household could independently organize its production and exercise control over outputs and production. Most importantly, the control rights over 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 to be delivered to the village government as payment for rent or taxes and as contribution to the village welfare fund and accumulation fund. The remainder is left with the households for consumption, saving and possibly for selling in the free market. The right to use land also entails an obligation to contribute labor for maintenance and construction of public infrastructure. The function of the village governments in the HRS includes the management of land contracts, maintenance of irrigation systems, and provision of agricultural services such as large farm machinery, product processing, marketing and technological advice and assistance (Lin, 1997; Wen, 1993, World Bank, 1985).

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, at the initial distribution, land was first classified into different grades. Thus, a typical farm household would contract 0.56 hectare of land fragmented into 9.7 tracts (Dong, 1996; Lin, 1997). As 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 15-30 years. As a result, various models of the land tenure system have evolved in different regions as an adaptation to local needs and conditions.<sup>4</sup>

## 2.2 Pricing and marketing of agricultural products

During the establishment of the HRS, increasingly more emphasis was given to market mechanisms for guiding production decisions in the agricultural sector, although the central planning was still deemed essential. The number of planned product categories and mandatory targets was reduced from 21 and 31 in 1978 to respectively 16 and 20 in 1981, and further to 13 in 1982. Moreover, restrictions on interregional trade of agricultural products by private traders were gradually loosened. Cropping patterns that fit local conditions and exploit comparative advantages were encouraged. As a consequence, both cropping patterns and intensity changed substantially between 1978 and 1984. The sown acreage of cash crops increased from 9.6 percent of the total in 1978 to 13.4 percent 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 and less smooth than expected, the market freedom enjoyed by Chinese farmers has increased significantly since then. In the early 1990s about two-thirds of China's marketable cereal production was purchased or sold in the form of free retails or wholesales at prices determined by market forces. The gap between market prices and quota prices has been gradually narrowed though the pace has

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<sup>4</sup> For more information on various innovative models of land tenure, e.g., see Dong (1996), Fahlbeck and Huang (1997), Wang (1993), Rural Sample Survey Office (1994), Chen and Han (1994), Lin Nan (1995).

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<sup>5</sup>. The irrigated land produces about 70 percent of grain output, most of cotton, cash crops, and vegetables. Thus, heavy dependence on irrigation is another unique feature of China's agriculture. 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 the major share of irrigation water has been delivered to the fields by gravity irrigation with the help of dams, reservoirs, canals, and irrigation systems, an increasing portion of irrigation water is being supplied by diesel and electric pumps. Machine-powered irrigation accounted for one quarter of the total irrigated area in 1965, increasing to two-thirds in 1993 (SSB, 1993, p. 349; Ministry of Water Conservation, 1994). As a consequence, irrigation equipment has been accounting for a large fraction of the total power consumed by agricultural machinery since the 1980s.

### 2.4 Labor-intensive production

It is generally accepted (Lindert, 1999; Wang, 1998; Dazhong, 1993) that land is an extremely scarce factor in China's agriculture, while capital is limited, and labor is relatively abundant. Although the percentage of labor force engaged in agriculture has been gradually falling from 93.5 percent in 1952 to 56.4 percent in 1993, the total number of agricultural workers doubled during the same period due to rapid population growth, up from 173 million in 1952 to 374 million in 1993, even though the rapid expansion of the rural industrial sector has created employment for more than 120 million rural workers since 1992. However, the growth in the absolute number of farm workers in the cropping sector persisted until 1984, and this trend was persisting by 1993 for the agricultural sector

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<sup>5</sup> There are two sets of farmland data in China. Most widely used is the data set published by State Statistical Bureau (SSB) in the *Statistical Yearbook of China*. Another data set was compiled by the State Land Administration (SLA), based on a land survey in the 1980s. SSB has noticed that its figures for cultivated areas may underestimate the actual extent. According to SSB, the area of cultivated and irrigated land in 1990 was only 95.7 and 47.4 million hectares, respectively, whereas the corresponding figures from SLA were 132.7 and 63.5 million hectares. Thus the irrigation share is similar on average but the differences between the estimates at province and national level are quite large (SSB, 1994, pp. 329 and 335; Fischer *et al.*, 1998).

as a whole (Lin, 1992, Table 4; SSB, 1997, pp. 94 and 400). In 1990, the average family farm managed only 0.42 hectare farmland but it had 1.73 laborers engaging in agriculture (Ministry of Agriculture, 1991).

Constrained by the unfavorable land/labor ratio, Chinese peasants historically could not but 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 like 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 excrements), 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 due to their high nutrient content and low cost<sup>6</sup>.

Chemical fertilizers have been increasingly used to improve crop yields owing to the rapid growth of domestic fertilizer production capacity and of fertilizer imports. Chemical fertilizer use in China has quadrupled since 1978. Since the early 1990s, China has emerged as the largest consumer, the second largest producer and as a major importer of chemical fertilizers in the world (FAO; SSB, 1989-1997). However, the average application of chemical fertilizer has remained modest, at 155 kilograms of nutrients per hectare in 1995, which is below the average level of East Asian developing countries and far below that in Japan and South Korea<sup>7</sup>. According to estimates of the World Bank (1997, p. 16), fertilizer applied in 1995, with an estimated value of 125 billion Yuan, was the major cash input in crop production. The rapidly increasing application of chemical fertilizer has been identified by many as a key factor contributing 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 fertilizer has been significant

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<sup>6</sup> We note 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.

<sup>7</sup> This rate is calculated on the basis of the State Land Administration's (SLA) figure of the total farmland area, which is about 132 million hectares in 1995. 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).

(e.g., among others, Kueh, 1984; McMillan *et al.*, 1989; Halbrecht and Gempe, 1990; Lin, 1992), partly through a mutual reinforcement between increasing application of chemical fertilizer and adoption of new crop varieties responsive to chemical fertilizers.

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

It may also need to be noticed in this connection that organic fertilizer is more than a mere substitute for chemical macro-nutrients. With its high content of organic matter and a 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 timely water supply. Finally, the tradition of careful use of organic fertilizers has made the transition to chemical fertilizers relatively smooth and easy in China in the 1960s and 1970s (Stone and Desai, 1989).

### 3. Crop-mix index and input response function

#### 3.1 Introduction

Our specification of the agricultural production relationships follows Keyzer (1998). We postulate a transformation function that is separable in outputs and inputs, with a crop-mix index for outputs and a response function for inputs. The crop-mix index is in CES form and the input response is specified as a generalized version of the common Mitscherlich-Baule (MB) yield function, whose maximal attainable output is obtained from an agro-ecological zone assessment. The input response distinguishes two types of land, irrigated and rainfed. Their yield potentials and cropping practices differ significantly. However, since as usual in agricultural sector modeling, the data on inputs is not differentiated by type of land use or by crop, and since data on crop output is not land-use type specific, we cannot estimate a transformation function for each land-type or crop separately, but rather must be satisfied with the estimation of a single transformation function applied for all crops and land-use types.

Let the subscript  $\ell$  denote observations (i.e., more than 2000 counties in our case),  $Y$  a  $\ell \times C$  vector of outputs,  $V$  a  $\ell \times K$  vector of non-land inputs, and  $A$  a  $\ell \times S$  vector of land uses with  $S$  different land quality types. The vector 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:

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

where  $Q(Y)$  is the crop-mix index, and  $G(V, A; x)$  the input response function. Function  $Q(Y)$  is taken to be linear homogeneous, convex, non-decreasing, and continuously differentiable, and  $G(V, A; x)$  is 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 were compiled per county. As discussed earlier, the transformation function is estimated in primal form rather than in the dual form with separate crop-specific supply functions, for two reasons. First, profit maximization may not be the relevant behavioral criterion for Chinese agriculture, and price data cannot capture the variability at county level since they are only available at provincial level and measured as a mix of procurement prices and free-market prices. The estimation is cross-section over counties, in volumes per unit area (represented by the corresponding lower case characters), i.e.:

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

where  $\varepsilon$  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 constant-elasticity-of-substitution (CES):

$$Q(Y_\ell) = \left( \sum_c (\alpha_c Y_{\ell_c})^{\alpha_0} \right)^{1/\alpha_0} \quad (3.3)$$

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  $\alpha_0 > 1$  guarantees the CES-function to be convex.

The specification also needs to be flexible in order to account for differences in cropping patterns across counties, say, in a county only 10 out of the 16 crops are being grown. This could be incorporated in various ways. One way would be to drop the crops from the crop-mix index, while scaling up the coefficients for the remaining crops in (3.3) through an additional parameter. However, doing this we must face the problem that in China the number of crop-mixes often outnumber the observations and two to four crops often cover about two-thirds of the total production value. To deal with this problem we introduce a distinction 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:

$$Q(Y_\ell) = (1 + \sum_m \mu_m M_{\ell m}) \left( \sum_{c \in C_\ell} (\alpha_c Y_{\ell c})^{\alpha_0} \right)^{1/\alpha_0}, \quad (3.4)$$

where  $\mu_m$  is an estimated scaling factor,  $M_{\ell m}$  is a zero-one dummy that associates the county to a particular scaling factor and  $C_\ell$  is the set for which  $Y_{\ell c} > 0$ . Each county has at most one non-zero 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 county level. It is specified as:

$$Q_\ell = f(V_\ell, H(A_\ell)) N(A_\ell, \bar{y}_\ell(x_\ell)). \quad (3.5)$$

where  $f(\cdot)N(\cdot)$  is a generalized Mitscherlich-Baule specification following Keyzer (1998), and  $H(\cdot)$  and  $N(\cdot)$  are the aggregate area and potential output index, respectively, which are specified as:

$$H_\ell(A_\ell; \delta) = \sum_s \delta_s A_{\ell s} \quad (3.6)$$

$$N_\ell(A_\ell, \bar{y}_\ell(x_\ell); \delta) = H_\ell(A_\ell; \delta) \bar{y}_\ell(x_\ell) \quad (3.7)$$

with  $\bar{y}_\ell(x_\ell)$  denoting the maximal attainable yield for given agro-ecological conditions  $x_\ell$ . This potential yield  $\bar{y}_\ell(x_\ell)$  is calculated as the maximal attainable production  $\bar{Y}_\ell(x_\ell)$  divided by land index  $H_\ell$ . Parameter  $\delta_s$  is preset and was not estimated. The input response function  $f(\cdot)$  in (3.5) is specified in product form, to allow for different input groups. The functional form is:

$$f(V_\ell, H(A_\ell)) = \prod_j f_j(V_\ell, H_\ell; \beta_j, \gamma, \rho_j)^{\theta_j} \quad (3.8)$$

with

$$f_j = 1 - \exp[-\beta_j - w_j(V_\ell, H(A_\ell; \delta); \gamma, \rho_j)] \quad (3.9)$$

where  $f_j$  is the  $j$ -th component of a Mitscherlich-Baule (MB) yield function and its exponent  $\theta_j > 0$  is such that  $\sum_j \theta_j = 1$ . This parameter  $\theta_j$  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 so as 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  $w_j$ .

$$w_j(V_\ell, H(A_\ell; \delta); \gamma, \rho_j) = \left( \sum_{k \in j} \gamma_k \left( \frac{V_{\ell k}}{H_\ell} \right)^{\rho_j} \right)^{1/\rho_j} \quad (3.10)$$

with  $\gamma_k \geq 0$  and  $\rho_j \leq 1$  ensuring concavity of  $w(\cdot)$ . 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  $\bar{y}_\ell(x_\ell)$  as will be explained in Section 4. However, cropping possibilities vary widely across China and also within the estimated regions, ranging from single cropping to triple rice cropping. The maximal attainable yield  $\bar{y}_\ell(x_\ell)$  alone is not sufficient to capture this variability. To account for these differences, cropping system zone variables  $Z_{\ell z}$  are introduced, where the subscript  $z$  indicates the cropping system zone. If for irrigated conditions a county is located in cropping system zone  $z$ , the value of the related variable is 1, and 0 otherwise. Then (3.5) becomes:

$$Q_\ell = Z_z f(V_\ell, H(A_\ell)) N(A_\ell, \bar{y}_\ell(x_\ell)) \quad (3.11)$$

with

$$Z_z = \sum_z \zeta_z Z_{\ell z}. \quad (3.12)$$

The outputs in (3.4) and the potential production in (3.5) are measured in different units of measurement.  $Y_{\ell c}$  is given in metric tonnes of produce, while the potential is given as cereal equivalent in metric tonnes of economic dry matter. Harmonization of the

dimensions is restored via the crop and county specific parameter ratio  $\alpha_c(1+\mu_m M_{\ell m})/\zeta_z Z_{\ell z}$ .

### 3.4 Computing implicit prices for aggregation

The transformation function enters the LUC-model for China after an aggregation procedure from county to region. Our approach is to assume “implicit” profit maximization, at implicit prices. These are the prices that would support the observed crop and input allocations under profit maximization. We interpret the gap between these prices and average market prices in the cities as processing margins, which we use in the aggregation procedure from county to region. Clearly, this procedure needs further empirical justification and we show in Section 5.5 that the resulting margins have a meaningful interpretation, i.e., that despite the institutional peculiarities in China we can indeed view the allocation decisions as being based on profit maximization, at prices governed by institutionally determined wedges.

Assuming profit maximization subject to 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  $V$  and corresponding aggregate output  $Q$  so as to maximize his revenue, at given prices of  $V$  and  $Q$ .

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

$$\begin{aligned} \max_{Y_{\ell c} \geq 0} \quad & \sum_{c \in C_\ell} p_{\ell c} Y_{\ell c} \\ \text{s.t} \quad & Q(Y_\ell) = \bar{Q}_\ell \end{aligned}, \quad (3.13)$$

with  $p_{\ell c}$  as the price of crop  $c$  in county  $\ell$ . The Lagrangean of this problem is:

$$L = \sum_{c \in C_\ell} p_{\ell c} Y_{\ell c} - \bar{P}_\ell (Q(Y_\ell) - \bar{Q}_\ell) \quad (3.14)$$

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

$$p_{\ell c} = \bar{P}_\ell \frac{\partial Q(Y_\ell)}{\partial Y_{\ell c}} = \frac{\bar{P}_\ell \bar{Q}_\ell}{Y_{\ell c}} \frac{(\alpha_c Y_{\ell c})^{\alpha_0}}{\sum_{c'} (\alpha_{c'} Y_{\ell c'})^{\alpha_0}}. \quad (3.15)$$

For the base year the county level price index  $\bar{P}_\ell$  has been calculated from provincial and national prices and county level production data (see annex I). In simulation runs with endogenous crop prices  $p_{\ell c}$  the index is calculated as:

$$P_\ell = \frac{1}{(1 + \sum_m \mu_m M_{\ell m})} \left( \sum_{c \in C_\ell} \left( \frac{p_{\ell c}}{\alpha_c} \right)^\sigma \right)^{\frac{1}{\sigma}} \quad (3.16)$$

with  $\sigma = \frac{\alpha_0}{\alpha_0 - 1}$ . The county specific relation between the base year price index and the

obtained under the maximizing producer assumption becomes:

$$\bar{P}_\ell = P_\ell (1 + \varepsilon_\ell^p) = P_\ell \left( 1 + \frac{\bar{P}_\ell - P_\ell}{P_\ell} \right), \quad (3.17)$$

and in simulation runs the estimated price index can replace the 'observed' index.

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

$$\max_{V_{\ell k} \geq 0, A_{\ell s} \geq 0} \bar{P}_\ell G(V_\ell, A_\ell) - \sum_k p_{\ell k} V_{\ell k} - \sum_s p_{\ell s} A_{\ell s}. \quad (3.18)$$

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

$$p_{\ell k} = \bar{P}_\ell \frac{\partial G(V_\ell, A_\ell)}{\partial V_{\ell k}} = \bar{P}_\ell \frac{\partial g(v_{\ell k})}{\partial v_{\ell k}}, \quad (3.19)$$

with  $v_{\ell k} = V_{\ell k} / H_\ell$  and

$$\frac{\partial g(v_{\ell k})}{\partial v_{\ell k}} = g_\ell \theta_j \frac{1 - f_{\ell j}}{f_{\ell j}} w_{\ell j}^{1 - \rho_j} \gamma_k v_{\ell k}^{\rho_j - 1}. \quad (3.20)$$

For land-use type s the marginal productivity is:

$$\begin{aligned}
p_{\ell_s} &= \bar{P}_\ell \frac{\partial G(\mathbf{V}_\ell, \mathbf{A}_\ell)}{\partial A_{\ell_s}} = \bar{P}_\ell \left( f_\ell \frac{\partial N(A_{\ell_s})}{\partial A_{\ell_s}} + N_\ell \frac{\partial f(\mathbf{V}_\ell, \mathbf{A}_{\ell_s})}{\partial A_{\ell_s}} \right) \\
&= \bar{P}_\ell \delta_s g(\mathbf{v}_\ell) \left( 1 - \frac{\partial g(\mathbf{v}_\ell)}{\partial v_\ell} \frac{v_\ell}{g(\mathbf{v}_\ell)} \right)
\end{aligned} \tag{3.21}$$

where

$$\frac{\partial g(\mathbf{v}_\ell)}{\partial v_\ell} \frac{v_\ell}{g(\mathbf{v}_\ell)} = \sum_j \theta_j \frac{1 - f_{\ell_j}}{f_{\ell_j}} w_{\ell_j} \tag{3.22}$$

and  $f_{\ell_j}$  and  $w_{\ell_j}$  are the same as defined by (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, which are discussed in the present section.

### 4.1. Crop outputs and procurement prices

The total annual output of grain, cotton, and oilseeds is available at county level (SSB and CDR, 1996). The published data were matched with county administrative codes as used in the LUC Project's database of China. Also available are output data and sown areas of wheat, rice, maize, sorghum, millet, other starchy crops, potato and other root crops, soybean, oilseeds, cotton, sugar beet, sugarcane, fiber crops, tobacco, tea, and fruit for 1989 but not for 1990. These data were compiled by the State Land Administration and provided to FAO. While the year 1990 represents rather well the average conditions of Chinese cropping agriculture during the period from 1985 to 1995, whereas the 1989-crop was fairly poor due to weather conditions, we use data for 1990 whenever possible. As a consequence, we had to disaggregate the data for grains in 1990 on the basis of crop-pattern distribution available for 1989. According to Chinese statistics, the aggregate termed *grains* includes wheat, rice, maize, sorghum, millet, other starchy crops, potato and other root crops, and soybean (five kilograms of potato 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:

$$q_c^{90} = G^{90} \cdot \frac{q_c^{89}}{G^{89}}, \quad (4.1)$$

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 county level for 1989 were available, and no output data for any year. The national average yield of 20.9 tons per hectare in 1989 was used (Xie and Jia, 1994, p. 103) to calculate vegetable output at county level.

Procurement prices at both provincial and national levels for wheat, rice, maize, sorghum, millet, soybean, oilseeds, cotton, sugarcane, fiber crops, tobacco, tea, and fruit were

extracted from *Yearbook of Price Statistics of China 1992* (SSB, 1992b, pp. 302-365). The procurement price for a crop is a quantity-share-weighted mean of quota prices, negotiated prices, and free-market prices. The procurement of commodities is done not only by government agencies, but also enterprises, social organizations, and trade companies. There is no price data for Hainan Province in this *Yearbook*. Prices in Guangdong were used as proxies for Hainan in view of the fact that Hainan Province had been 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 following the information in the national price data for China listed in the FAO-AGROSTAT database. Again with reference to FAO-AGROSTAT, one third of wheat price is used as a proxy for the price of potato 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, provincial capital city) in most of the provinces. Representative vegetables for each province were selected and the representative price for the vegetable category is the arithmetic mean of the various prices.

With the steps described in the previous paragraphs, price data could be obtained for all major crops of each province. However, the price information for some minor crops was still missing, and these 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 county level are available in the LUC project for various years between 1985 to 1994. They include agricultural labor force, total power of agricultural machinery, total number of large animals, and chemical fertilizer applied. In the following we will only discuss the 1990 data since these were used in estimation. A data problem arises from the fact that in Chinese statistics,

broad agriculture consists of farming, forestry, animal husbandry, fishery, and sideline production. We attribute non-land inputs to the crop sector based on the share of crop agriculture in broad agriculture. The total output value of broad agriculture is available at county level. Availability of crop output 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 agricultural labor force and power of agricultural machinery<sup>8</sup>.

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 (sub-)urban counties the number of agricultural workers per hectare of agricultural land is extremely high (more than 10). Machine power per hectare is likewise biased due to the fact that transport vehicles and other processing machineries are included in the statistics. Nonetheless these counties were initially included in the estimations. After the first round some of the counties biased the estimation substantially and these observations were dropped. Secondly, prices are at provincial level and, consequently, the variability at county level depends on quantities alone.

Whereas "chemical fertilizer applied" can safely be attributed to crop farming rather than to forests or pastures, organic fertilizer data can only be derived by imputation. We follow the approach in Wen (1993, Tables 4 and 5) and assume that (i) 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 are 0.8 and 0.4, respectively, in 1990; the nutrient content rate of night soil is 0.011, i.e., 1.1 percent; (ii) 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; and (iii) hog manure is assumed to be 2 tons per animal per year, with a utilization rate 0.8, and a nutrient content rate of 0.014. No systematic data is available on other sources of organic fertilizer such as green fertilizer, oil cake, compost, and mud and pond manure. The resulting estimate of the national total at 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, p. 95). In some counties, where

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<sup>8</sup> We used the total number of large animals as a proxy for draught animals. However, due to the poor performance of this proxy in all estimations, we finally had to drop it from the estimation.

animal husbandry plays a key role, the manure of large animals may dominate in total organic fertilizer, and animal manure often is 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 raw organic fertilizer manageable per worker per year (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 China's State Land Administration (SLA). The national total of cultivated land areas obtained by summation over counties is some 135 million hectares, which is about 40 million hectares higher than the corresponding national figure published in the *Statistical Yearbook of China* (SSB, 1991, p. 314), but is quite consistent with the figure recently compiled by the SLA, based on a detailed land survey<sup>9</sup> (see Fischer *et al.*, 1998). In addition to statistical data, the LUC project database includes several digital coverages for China, including climate, land use, vegetation, altitude and soils. These were compiled, re-organized and edited jointly with the Chinese collaborators in the LUC project to provide a basis for biophysical assessments of surface hydrology, vegetation distribution, and for estimating potential yields of major crops<sup>10</sup>. 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 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 suggested by the statistical figures. In some areas, when rainfall comes in time for cropping and in adequate amounts, irrigation is not necessary and the differentiation between irrigated and rain-fed land becomes unimportant. And conversely, when the water shortage is severe, irrigation may be impossible despite existing irrigation facilities.

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<sup>9</sup> Personal communications with Chinese officials suggest that the farmland data compiled by 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 sub-section are derived from various publications of China's State Statistical Bureau.

<sup>10</sup> 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/>

### 4.3. Potential yields

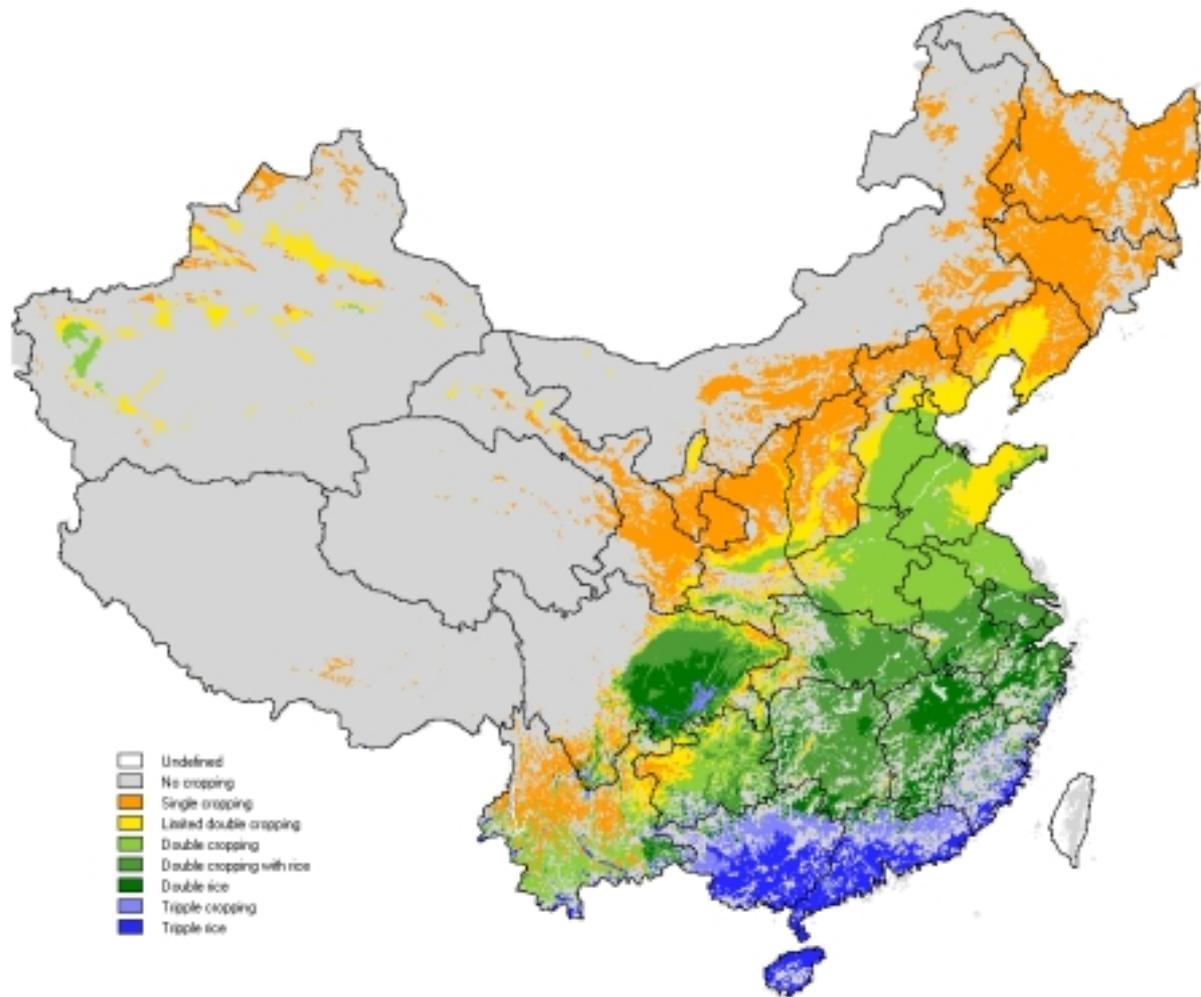
Biophysical reality enters the input-output relationships through a potential output index  $N(A, \bar{y}(x))$  (equation 3.7) and the cropping system zone index  $Z_\ell$  (see equation 3.12), and involves the estimation of potential production  $\bar{Y}_{\ell,s}(x)$  by county, and land-use type.

After conducting a detailed agro-ecological zones (AEZ) assessment across counties in China, the 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 in Fischer *et al.* (2000). Next, to arrive at the potential yields to be used in the production function (equation 3.5), a suitable aggregation had to be performed, in three steps:

- classification of each 5x5 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, and
- aggregation of results at 5x5 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 irrigation conditions are shown in Figure 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, respectively. In Zone 2, temperature profiles permit cultivation of two short-cycle crops or relay cropping systems. Examples are wheat and millet grown in sequence, or wheat/maize relay crops. Yields are calculated separately for crops adapted to cool and to moderately warm or warm conditions. Potential yields at 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 winter crop (including a dormancy period) and crops such as maize, soybean or sweet potato grown in the warm season. Potential annual yields are constructed from these two pools.

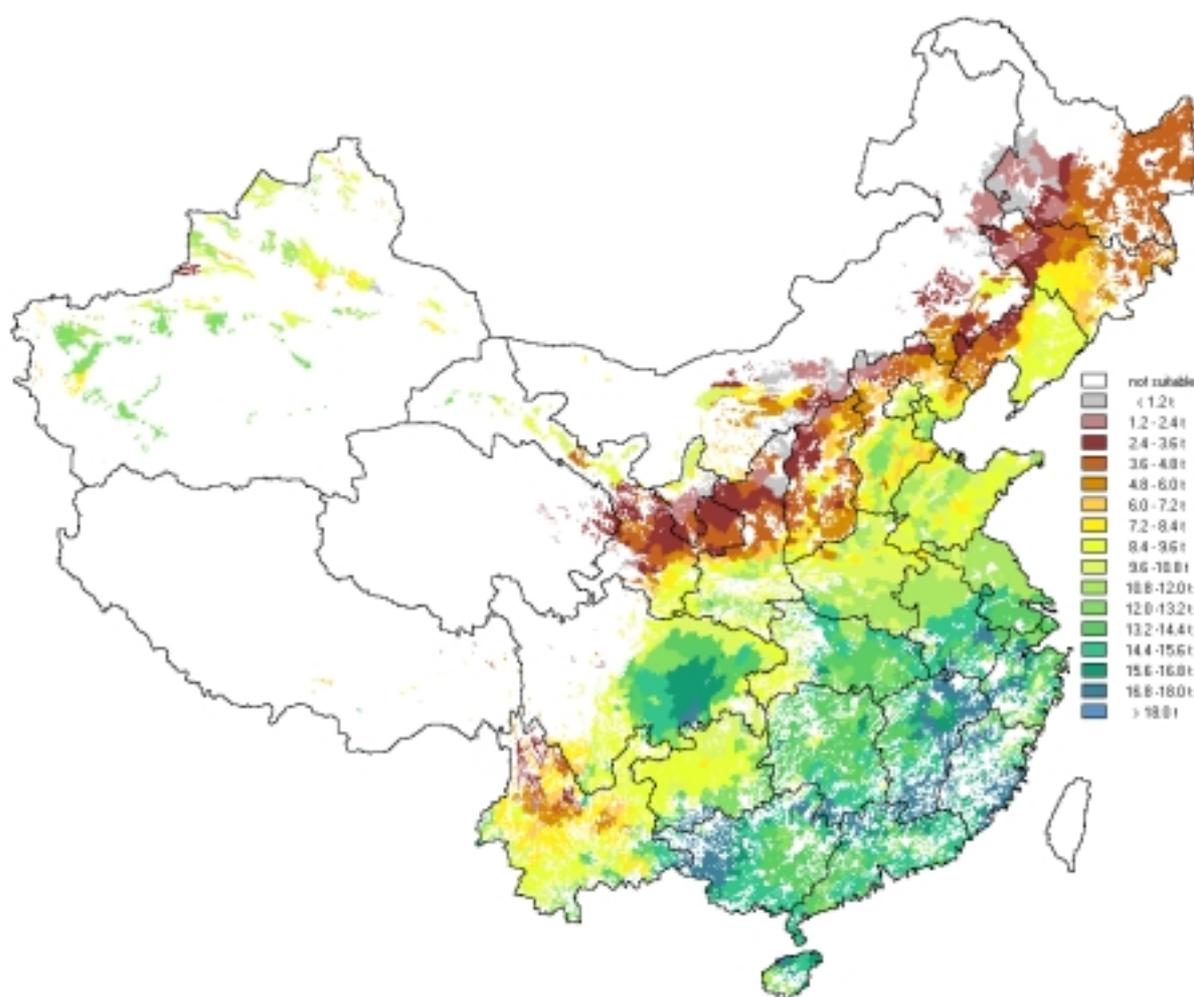


**Figure 1. Multiple cropping zones under irrigated conditions.**

Zone 4 has double cropping similar to the previous zone, except that the main summer crop such as rice or cotton demands more heat. Zone 5 is generally found south of the Yangtse, 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 less are considered when calculating annual output. Zone 6 occurs in southern China and allows three sequential crops to be grown. A typical example is the cropping system with one crop of winter wheat and two rice crops grown in spring to autumn. In this case, only short cycle crops can be considered.

**Table 1. Number of counties per cropping system zone by region**

Region	North	North-East	East	Central	South	South-West	North-West/ Plateau
Single cropping	94	138				62	200
Limited double	111	21		10		64	48
Double cropping	287		73	14		102	22
Double with rice			115	171	18	90	
Double rice			41	62	39	66	
Triple cropping					116		
Triple rice					78		
Total	492	159	229	257	251	384	270



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

Finally, Zone 7 delineates the most southern part of China where tropical conditions prevail, and allows three crops to grow that are well adapted to warm conditions, e.g., rice. In our calculation, this condition is satisfied when the growing season is year-round and

annual accumulated temperature (above 10°C) exceeds 7000 degree-days. Only crop types requiring less than 120 days until harvest are considered when the MCI exceeds 3.0.

Table 1 shows the number of counties in each cropping system zone under irrigated conditions to be used in the estimation. If there were only very few counties in a cropping system zone of a particular region the observations were added to the adjacent zone. Figure 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 each county or even in each region. To capture this aspect, scaling parameters were introduced into the crop-mix index function (equation 3.4). Table 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 2. Share of crop in total revenue and number of counties growing the crop**

Crop	North		North-East		East		Central		South		South-West		North-West Plateau /	
	%	Obs	%	Obs	%	Obs	%	Obs	%	Obs	%	Obs	%	Obs
Rice	32	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	154		18		57		79		65	1.8	186
Oth. strchy	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	256	1.9	250	3.1	379	2.4	250
Soybean	2.9	492	11.7	158	3	223	1.8	256	1.5	246	1.4	371	4.1	197
Oilseed	13.8	385	0.2	21	7.2	184	7.1	198	0.1	34	1.6	97	2.1	45
Cotton	6.2	490	2.5	156	6.4	228	5.4	257	4.2	251	6.4	373	8.6	270
Sugarcane		136	1.6	106	0.2	188	0.6	234	7.4	249	1.7	296	1.9	132
Fibre	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	383	5.7	253
Vegetab.	7	491	8.4	158	9	229	8.9	257	18	250	13.5	374	7.2	262
Number of counties		492		159		229		257		252		384		270

Table 2 does not capture the broad variation of over 400 crop combinations, which enter the model through the crop (-mix) variables  $M_m$ . Their definition is listed in Table 3. Guiding principles in the definition of crop-mix variables were: (i) not to exceed a total of 4 crop-mix parameters, and (ii) to give missing major crops priority over the less important ones. Each county has at most one nonzero crop-mix dummy. Table 4 presents the results of these crop-mix definitions.

**Table 3. Definition of crop-mix variables  $M_m$  (entries are crops missing)**

	Mix 1	Mix 2	Mix 3	Mix 4	No mix
North	Wheat	Maize/ Cotton/ Fruit	$\geq 3$ smaller crops	-	All other cases
North-East	Maize/ Rice/ Soybean/ Vegetables	Wheat	$\geq 3$ smaller crops	-	All other cases
East	Rice or Wheat	$\geq 5$ smaller crops	-	-	All other cases
Central	Rice/ Vegetables/ Cotton	$\geq 3$ smaller crops	-	-	All other cases
South	Rice/ Vegetables/ Fruit/ Sugarcane	$\geq 3$ smaller crops	-	-	All other cases
South-West	1 of Rice/ Vegetables/ Maize/ Wheat	2 or 3 of Wheat/ Rice/ Vegetables/ Maize	-	-	All other cases
North-West / Plateau	1 of Wheat/ Maize/ Fruit/ Vegetables	2 or 3 of Wheat/ Maize/ Fruit/ Vegetables	4 or 5 smaller crops	$\geq 6$ smaller crops	All other cases

**Table 4. County number corresponding to the crop-mix variables by region**

	Region						
	North	North-East	East	Central	South	South-West	North-West / Plateau
None	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

#### 4.5. Data checking

Multiple checks were conducted in order to improve data reliability and consistency. This was done on the basis of checking various relative indicators such as the irrigation ratio, land per laborer, land per capita, output per sown hectare, and each non-land input per hectare and per laborer. Occasionally, errors in the original publications could be corrected by comparison of different data sources. In some cases missing or dubious data could be

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

**Table 5. Observations per region**

	Regions							Total
	North	North-East	East	Central	South	South-West	North-West / Plateau	
All counties	510	184	244	275	272	402	491	2378
Missing data	13	25	15	18	21	18	212	322
Outliers (Labor/Machinery)	5	0	0	0	0	0	9	14
For estimation	492	159	229	257	251	384	270	2042

Eventually, of the 2378 administrative units contained in the LUC database in total, 2042 counties could be retained in the study, i.e., data were complete and were judged sufficiently reliable to be used for the output side as well as the input side of the estimation. Table 5 gives an account by region. Incomplete county level records eliminated 322 counties, and outliers mainly for labor and machinery figures eliminated another 14 (see also Section 4.2 above). These outliers were concentrated in the North, Plateau and North-East 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 North-West region based on the similarity of cropping zone pattern.

## 5. Results from estimation

Parameters of the model, which was described in Section 3, were estimated by Nonlinear Least Squares (NLS) for each region separately, except that the North-West region and Plateau (i.e., a few counties in Qinghai Province) were treated jointly because the number of valid observations (some 20) was too low for the Plateau region to be estimated separately. The presentation of results proceeds as follows. In Section 5.1, we check whether the error term meets the statistical requirements, which permit to consider NLS as a maximum likelihood estimator. Next, we discuss the estimation results of the input response function  $G$  (Section 5.2). Coefficient values of the output index  $Q$  are reported in Section 5.3. Finally, in Section 5.4 we present and discuss the spatial distribution of calculated implicit (shadow) prices and in Section 5.5 of the marginal productivity of input factors.

### 5.1 Analysis of error term

To test whether Nonlinear Least Squares amounts to maximum likelihood estimation, we check normality, homoscedasticity and independence of the error term. We apply two tests, one parametric and one non-parametric. 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. Secondly, we check whether errors might be spatially correlated, albeit locally. This is done by applying a spatial non-parametric (kernel density) regression (Bierens, 1987; Keyzer and Sonneveld, 1997) regressing the error term on longitude and latitude of the counties. For each county, the estimated value is calculated, the derivative with respect to longitude and latitude and the estimated probability of wrong sign for that derivative is calculated. Lack of spatial correlation finds expression in frequently changing signs of the derivatives and a high average probability of wrong sign of the derivatives.

Table 6 presents the Shapiro-Wilk statistic. The normality test is passed at 5 percent 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 enough to 0.5, implying that the error term could vary in any direction. Therefore, there is no need to correct for spatial

correlation of errors in the regression and that homoscedasticity and independence can be assumed.

**Table 6. Tests on the error term**

Region	North	North-East	East	Central	South	South-West	North-West / 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

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

## 5.2 Input response

Next, we report on the coefficient values and their likelihood ratios and on the elasticities of the input response equations, recalling that these were actually estimated simultaneously with the output mix equations. The likelihood ratio is used to check the robustness of the coefficients.

Let us briefly recapitulate its main principles first (see Gallant, 1987; Davidson and MacKinnon, 1993). We denote model parameters by  $\zeta_1, \zeta_2$ . Under our null hypothesis  $H_0$ :

$\zeta_1 = \bar{\zeta}_1$  and  $\zeta_2$  unrestricted while under the alternative  $H_1$ : both  $\zeta_1$  and  $\zeta_2$  are unrestricted. With maximum likelihood estimation, the significance level of an estimated

parameter  $\hat{\zeta}_1$  can be determined by an  $F$ -test:  $F(j, n - m) = \left( \frac{S(\bar{\zeta}_1, \tilde{\zeta}_2)}{S(\hat{\zeta}_1, \hat{\zeta}_2)} - 1 \right) \cdot \frac{n - m}{j}$ , 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  $S(\bar{\zeta}_1, \tilde{\zeta}_2)$  is the residual sum of squares for given

reference value  $\bar{\zeta}_1$  and free  $\tilde{\zeta}_2$ , corresponding to maximization of the restricted likelihood

function. Critical value for the region with smallest sample size (i.e., the North-East

region)  $F(1, 159)$  at 0.95 is 3.83.

As a reference value we use 50 percent<sup>11</sup> of the original estimate  $\hat{\zeta}_1$ , as opposed to the usual reference value zero because the function form is given and all variables have to enter the welfare model eventually. Hence, we need to assess the robustness of the estimated parameter value, rather than deciding whether the variable should be included at all.

### *Coefficients*

Table 7 presents the estimated coefficients of the input response function index G, their corresponding likelihood ratios (LR, in *italics*), and the number of observations in each region. Clearly, for parameters with zero value no likelihood ratio can be calculated. Since  $\sum_j \theta_j = 1$  no LR for  $\theta_{\text{Nutrient}}$  is estimated. As the parameter  $\delta_{\text{Rainfed}}$  is by definition equal to unity it has no LR value.

**Table 7. Estimated coefficients for the input response function**

Coefficient	Region						
	North	North-East	East	Central	South	South-West	North-West / Plateau
$\zeta_{\text{single cropping}}$	0.939 <i>33.8</i>	182.131 <i>136.6</i>	-	-	-	3.050 <i>258.0</i>	40.205 <i>129.3</i>
$\zeta_{\text{limited double}}$	0.892 <i>41.8</i>	169.202 <i>75.0</i>	-	5.150 <i>92.5</i>	-	2.217 <i>208.2</i>	32.751 <i>151.3</i>
$\zeta_{\text{double cropping}}$	0.841 <i>43.6</i>	-	5.983 <i>711.4</i>	4.353 <i>159.9</i>	-	2.111 <i>275.5</i>	33.862 <i>154.9</i>
$\zeta_{\text{double with rice}}$	-	-	5.768 <i>793.6</i>	3.502 <i>595.0</i>	2.806 <i>111.8</i>	1.891 <i>32.8</i>	-
$\zeta_{\text{double rice}}$	-	-	5.169 <i>636.0</i>	2.887 <i>2077.7</i>	2.553 <i>178.8</i>	1.742 <i>62.9</i>	-
$\zeta_{\text{triple cropping}}$	-	-	-	-	2.365 <i>30.5</i>	-	-
$\zeta_{\text{triple rice}}$	-	-	-	-	2.595 <i>78.7</i>	-	-

<sup>11</sup> The alternative values against which the estimated values are tested read:  $\theta_{\text{Power}} = .5$ ,  $\zeta_z = 1$ ,  $\mu_m = 0$ ,  $\rho_{\text{Power}} = -1.5$ ,  $\rho_{\text{Nutrient}} = .7$  or  $1$ . and  $\alpha_0 = 2$ . For  $\delta_{\text{Irrigated}}=1$ , the ratio between the potential yield on irrigated land to the potential yield on rain-fed land is used as the alternative, in the other cases if  $\delta_{\text{Irrigated}}=1$  is the hypothesis. Leading to the values  $\delta_{\text{Irrigated}} = 1.00, 1.00, 1.05, 1.04, 1.03, 1.16$  and  $1.00$ , respectively, for the various regions.

**Table 7. Estimated coefficients for the input response function (cont.)**

Coefficient	Region						
	North	North-East	East	Central	South	South-West	North-West / Plateau
$\theta_{\text{Power}}$	0.320 <i>376.6</i>	0.700* <i>772.9</i>	0.430 <i>4.8</i>	0.365 <i>115.4</i>	0.341 <i>160.2</i>	0.300* <i>210.7</i>	0.555 <i>22.7</i>
$\theta_{\text{Nutrient}}$	0.680	0.300	0.570	0.635	0.659	0.700	0.445
$\beta_{\text{Power}}$	0.000	0.000	0.013 <i>20.8</i>	0.001 <i>68.7</i>	0.005 <i>122.7</i>	0.006 <i>33.9</i>	0.001 <i>16.8</i>
$\beta_{\text{Nutrient}}$	0.000	0.031 <i>2.8</i>	0.005 <i>96.6</i>	0.000	0.000	0.013 <i>15.4</i>	0.003 <i>10.6</i>
$\rho_{\text{Power}}$	-0.250* <i>43.4</i>	-0.250* <i>126.1</i>	-0.250* <i>15.5</i>	-0.250* <i>20.4</i>	-0.250* <i>24.1</i>	-1.630 <i>74.6</i>	-1.265 <i>48.9</i>
$\rho_{\text{Nutrient}}$	0.700* <i>30.8</i>	0.700* <i>17773.5</i>	1.000* <i>16.8</i>	1.000* <i>3552.1</i>	1.000* <i>243.1</i>	1.000* <i>255.3</i>	0.700* <i>3.2</i>
$\gamma_{\text{Labor}}$	0.161 <i>30.0</i>	2.062 <i>14.5</i>	0.464 <i>15.7</i>	0.389 <i>50.2</i>	0.291 <i>40.9</i>	3.010 <i>22.5</i>	7.856 <i>16.6</i>
$\gamma_{\text{Machine}}$	0.807 <i>446.5</i>	2.141 <i>12.1</i>	1.024 <i>153.5</i>	1.779 <i>2264.7</i>	1.457 <i>817.3</i>	3.179 <i>34.9</i>	23.589 <i>22.6</i>
$\gamma_{\text{Chemicals}}$	3.235 <i>38.0</i>	0.337 <i>10.8</i>	0.160 <i>549.5</i>	1.578 <i>826.3</i>	0.728 <i>174.4</i>	0.934 <i>12.8</i>	0.120 <i>12.5</i>
$\gamma_{\text{Organic}}$	1.481 <i>37.8</i>	0.025 <i>11.2</i>	0.135 <i>97.3</i>	0.770 <i>75.5</i>	0.623 <i>28.3</i>	0.387 <i>37.8</i>	0.029 <i>13.8</i>
$\delta_{\text{Irrigated}}^1$	2.110 <i>35.5</i>	1.590 <i>4.9</i>	1.000 <i>117.2</i>	1.000 <i>54.4</i>	1.000 <i>28.7</i>	1.000 <i>30.6</i>	2.210 <i>22.2</i>
$\delta_{\text{Rainfed}}^1$	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, <sup>1</sup> preset value

As described in Section 3.3, the area index  $H(A)$  is preset before estimation. The parameter  $\delta_{\text{Irrigated}}$  converts irrigated land into rain-fed equivalent. It is chosen on the interval between unity and the ratio of potential yield on irrigated land to potential yield on rain-fed land and its significance was assessed (see previous footnote). The estimation results for the North-East region are generally slightly deviant on the input side. The quality of the input data and potential production in North-East is probably causing this result. Except for  $\beta_{\text{Nutrient}}$  in North-East all parameters are significant at 95 per cent level.

Not surprisingly, the input specific parameters  $\gamma$  show a large range of variability across regions, justifying estimation by region as opposed to a pooled estimation for China as a

whole. For the Northern regions, i.e. North-West/Plateau, North and North-East, fertilizer substitution is at the lower bound and relatively inelastic (elasticity of substitution  $\epsilon_{\text{Nutrient}} = 3.33$ ). Generally, the constants  $\beta$  of the input groups are small or zero. The upper bound for  $\rho_{\text{Power}}$  of -.25 is in effect for five regions. The substitution elasticities for the power-related inputs range from 0.38 in South-West to 0.80 in most other regions. .

### *Elasticities and marginal values*

As a further description of the results from estimation, we present in Table 8 the output elasticities by input category, evaluated at the regional mean (see Appendix II for a specification of the analytical form of elasticities). Since the input response function  $G$  is linear homogeneous of degree one in  $(V, A)$ , the elasticities of the inputs add up to unity.

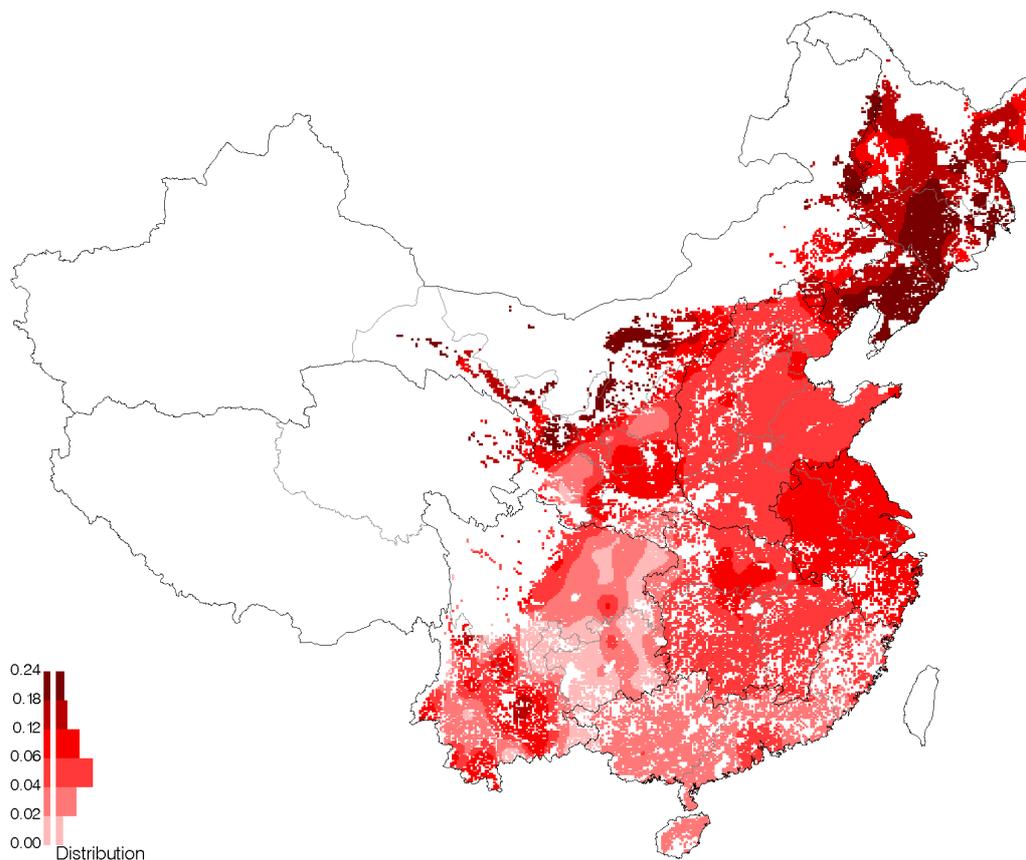
**Table 8. Output elasticities of land and non-land inputs at the regional mean**

Region							
Input	North	North-East	East	Central	South	South-West	North-West / 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
<i>Power</i>	<i>0.300</i>	<i>0.332</i>	<i>0.311</i>	<i>0.333</i>	<i>0.238</i>	<i>0.239</i>	<i>0.431</i>
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
<i>Nutrient</i>	<i>0.393</i>	<i>0.127</i>	<i>0.513</i>	<i>0.446</i>	<i>0.560</i>	<i>0.590</i>	<i>0.251</i>
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
<i>Land</i>	<i>0.307</i>	<i>0.541</i>	<i>0.176</i>	<i>0.221</i>	<i>0.202</i>	<i>0.171</i>	<i>0.318</i>
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 results suggest a differentiation into three zones. First, the Southeast part of China, i.e., regions East, Central, South and to some extent South-West. They 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, while labor has a small contribution to the output index. Second, we identify the regions North and North-West/Plateau where the similarity between the elasticities manifests mainly in their pattern with respect to the non-land inputs and not so much in their levels.

The levels of elasticities in North are comparable to the first zone. Finally, in the remaining region, North-East, the picture is different with the highest elasticity for labor.

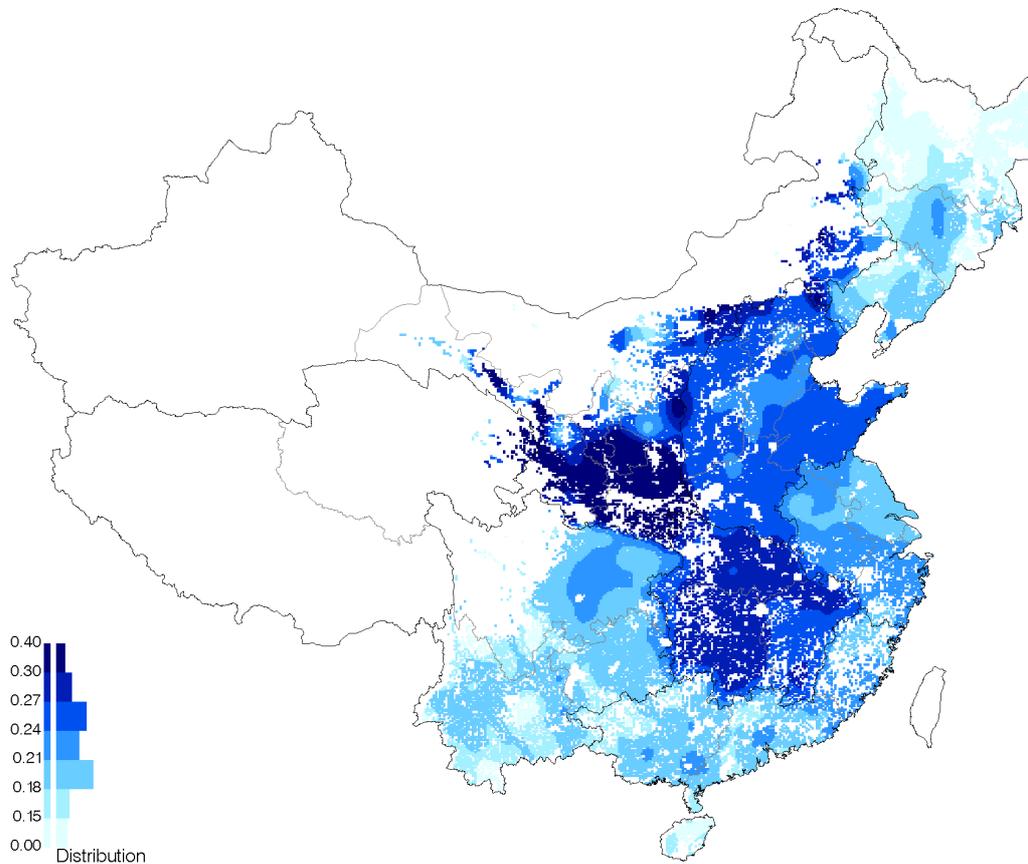
The elasticities of land-use types might convey the wrong impression that investment in irrigation in North-East, South-West and North-West/Plateau is not profitable. In fact the lower elasticities for irrigated land in some region merely reflects the lower area under irrigation (see Appendix II.2). For example, in North-East rain-fed agriculture is the dominant land-use type (78 percent) and  $\delta_{\text{Irrigated}}$  is 1.59 resulting in a ratio of the rain-fed over irrigated land of about 2.9. To assess the relative productivity of investment into irrigated and non-irrigated, a common area basis is needed. The two lines at the bottom of Table 8 measure the percentage increase in output if the land basis expands by one percent of irrigated and non-irrigated land, respectively. Since  $\delta_{\text{Irrigated}}$  exceeds  $\delta_{\text{Rainfed}}$ , irrigation appears to be more productive.



**Figure 3. Elasticity for labor**

Figure 3 and 4 map the county level elasticities for labor and machinery and seems to confirm the spatial pattern of the regional averages. The maps are computed on the basis of kernel density regression as in Keyzer and Sonneveld (1997). The histogram on the left

of each panel shows the percentage shares of the colored areas. A combined mask of estimated counties and agricultural areas as given by Figure 1 is applied.



**Figure 4. Elasticity for machinery**

As a further characterization of the differences across regions, we calculate the marginal values (see Table 9). These reflect the variability of implicit wages, rental cost of 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 densely populated areas of the Central and South regions where marginal returns to land are relatively high for both irrigated and rain-fed land. Despite its dense population, the East region reflects, with the relatively high marginal value of labor, the attractiveness of the more industrialized area.

**Table 9. Marginal values in Yuan at the mean**

Derivative	Region						
	North	North-East	East	Central	South	South-West	North-West / Plateau
$\partial G/\partial V$							
Labor (person)	113.90	580.05	242.11	125.62	88.83	41.63	160.20
Machinery (kW)	429.76	348.17	614.77	1086.19	784.91	1056.26	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
$\partial G/\partial A$							
Irrigated area farmland (ha)	1329.98	1190.84	862.63	1296.18	871.70	490.13	539.93
Rain-fed area farmland (ha)	630.32	748.95	862.63	1296.18	871.70	490.13	244.31

### 5.3 Output index

The coefficients of the output index function  $Q$  appear in Table 10. For the major staple crops (rice, wheat and maize) they generally come out very similar across regions. Deviations are mainly due to fact that certain crops are sometimes a major crop in one region and a minor in another. Wheat and maize are outliers in opposite directions in South where they contribute less than 1 and 1.6 percent to total crop revenue, respectively. Wheat can only be grown on a few scattered areas in Fujian and Guangdong. 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 basket of various kinds. The crop-mix correction factors  $\mu_m$  vary across regions and crop-mixes. Most are negative as expected, especially those associated with a major crop. Other crop-mix parameter can be positive since some of the regional minor crops are a major crop at county level. The significance level for most parameters is well above 95 per cent.

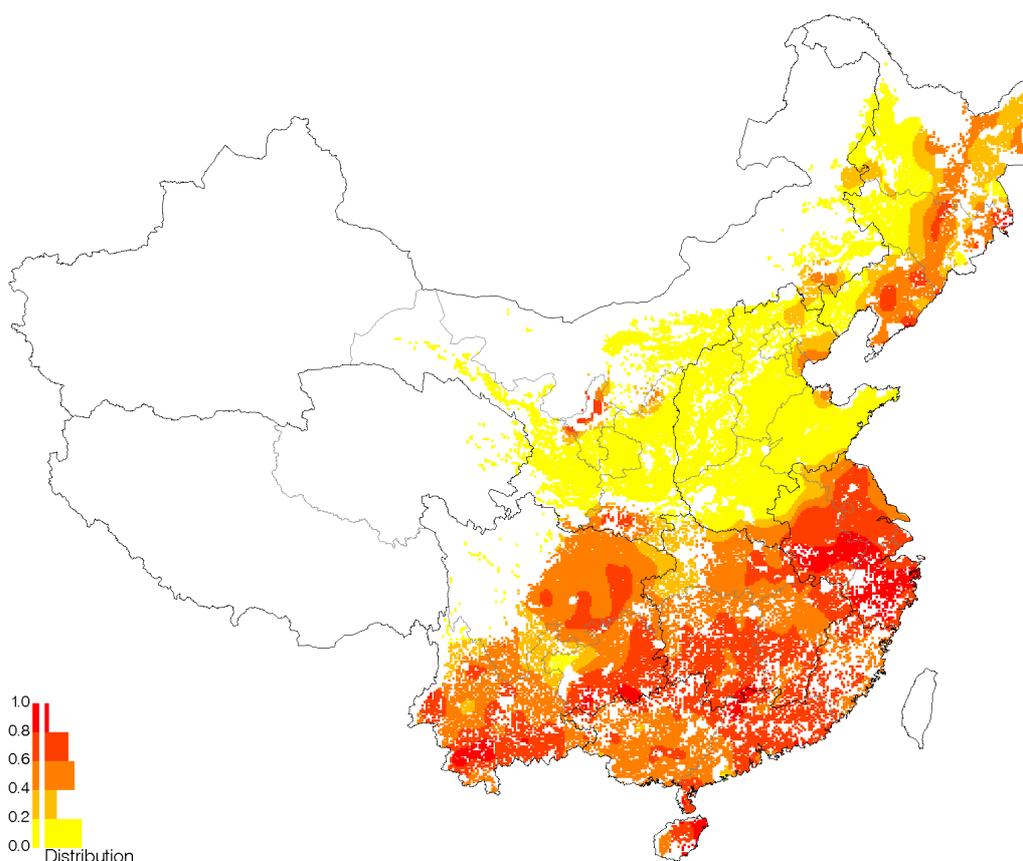
**Table 10. Estimated coefficients for the output function**

Region	North	North-East	East	Central	South	South-West	North-West / Plateau
$\alpha_0^1$	1.500 46.6	1.500 25.4	1.500 29.9	1.500 35.6	1.500 35.1	1.500 74.4	1.500 42.7
$\alpha_{\text{Rice}}$	0.780 36.4	0.727 1.3	0.892 199.8	0.752 281.8	0.712 111.4	0.839 93.2	0.890 18.3
$\alpha_{\text{Wheat}}$	1.171 163.7	0.881 5.0	1.099 21.0	1.374 32.3	5.425 33.1	1.035 28.5	1.024 17.0
$\alpha_{\text{Maize}}$	1.433 38.4	0.668 11.1	3.863 14.5	10.922 23.5	13.532 23.0	0.030* 31.9	0.030* 16.5
$\alpha_{\text{Sorghum}}$	2.095 43.7	0.168 5.0	0.030* 14.5	0.030* 17.3	49.332 20.5	0.030* 30.3	0.793 16.9
$\alpha_{\text{Millet}}$	0.720 48.7	0.586 9.4	0.934 16.0	0.806 17.7	2.346 39.6	1.205 68.5	0.672 19.7
$\alpha_{\text{Other starchy}}$	0.944 30.9	3.588 6.9	0.714 14.2	2.592 16.5	0.030* 18.8	0.592 33.3	0.159 17.6
$\alpha_{\text{Root crops}}$	0.383 30.2	0.030* 5.9	0.534 14.7	0.724 16.5	0.030* 19.9	0.841 33.1	0.959 16.2
$\alpha_{\text{Soybean}}$	2.624 33.7	1.231 3.9	3.467 15.3	6.385 17.8	0.030* 20.1	0.030* 30.0	0.030* 16.9
$\alpha_{\text{Oilseed}}$	1.324 28.2	0.503 5.4	3.300 17.7	4.417 23.9	7.972 31.3	2.361 29.1	0.526 17.0
$\alpha_{\text{Cotton}}$	6.796 46.8	35.730 5.5	10.066 17.6	9.360 22.0	6.079 22.7	18.836 33.3	11.477 22.0
$\alpha_{\text{Sugarcane}}$	1.043 35.9	0.030* 5.0	0.536 14.7	0.342 15.8	0.201 24.1	0.212 49.6	0.563 20.7
$\alpha_{\text{Fiber}}$	4.802 34.6	0.030* 5.0	2.889 13.7	2.577 15.3	13.924 21.8	11.246 24.2	39.267 16.3
$\alpha_{\text{Tobacco}}$	3.203 31.5	8.088 7.3	0.030* 14.3	7.062 32.8	6.844 23.4	4.713 45.5	1.391 18.3
$\alpha_{\text{Tea}}$	31.912 32.8	-	10.469 17.7	12.199 17.0	17.698 24.6	11.082 31.7	0.030* 17.2
$\alpha_{\text{Fruit}}$	1.674 30.1	1.241 7.3	1.427 15.3	2.504 24.1	1.901 21.5	2.206 28.9	1.885 15.3
$\alpha_{\text{Vegetables}}$	0.346 42.1	0.267 7.9	0.364 26.9	0.484 29.9	0.347 18.9	0.461 64.2	0.335 19.4
$\mu_{\text{Mix 1}}$	-0.182 41.6	-0.182 7.7	-0.076 12.5	-0.014 14.1	0.121 20.8	-0.215 35.1	-0.376 34.4
$\mu_{\text{Mix 2}}$	-0.083 41.8	0.203 10.9	-0.119 29.8	-0.043 20.8	0.054 24.0	-0.031 30.7	-0.022 16.6
$\mu_{\text{Mix 3}}$	-0.014 32.3	0.021 5.0	-	-	-	-0.034 35.7	-0.043 21.3
$\mu_{\text{Mix 4}}$	-	-	-	-	-	-	0.019 17.6

\* parameter at bound, <sup>1</sup> preset value

## 5.4 Implicit prices

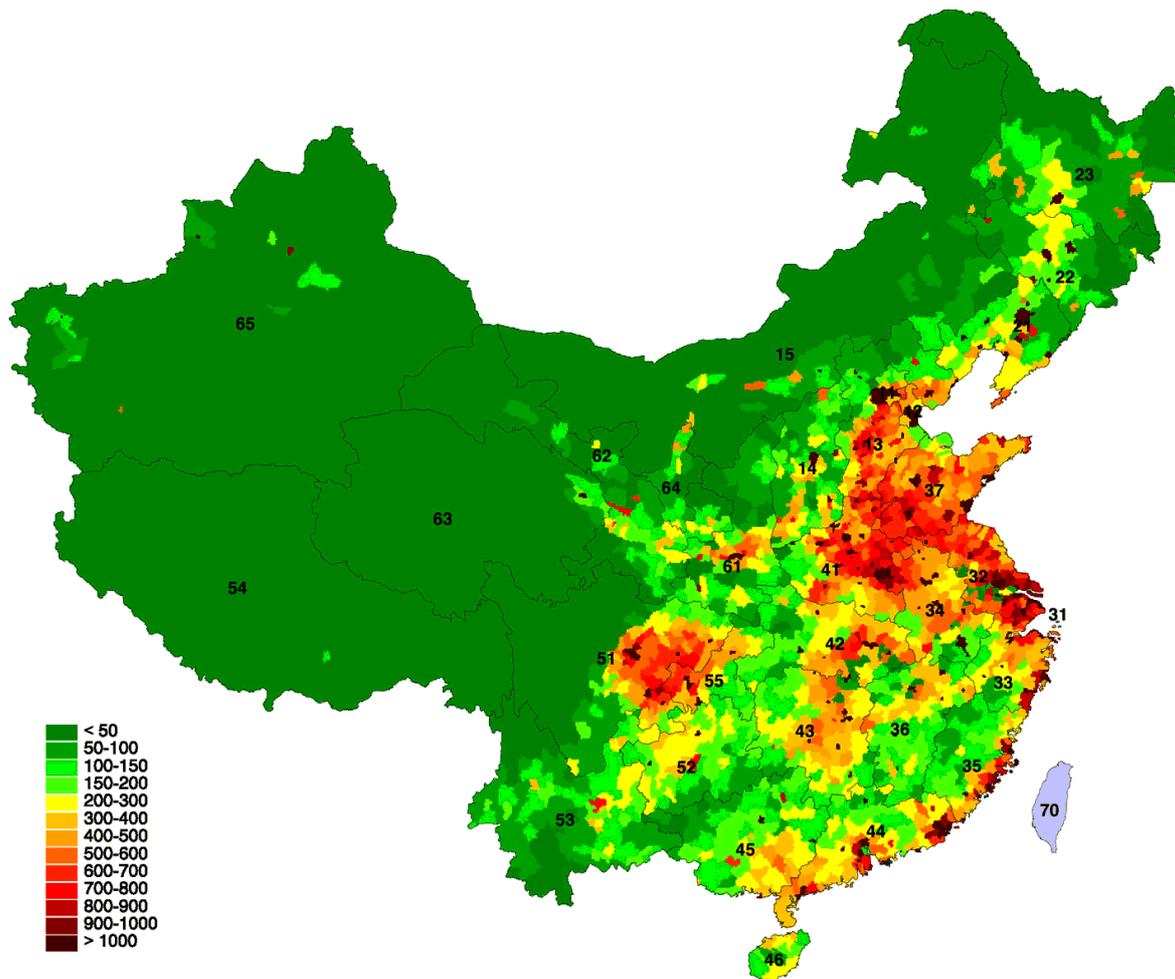
We are now ready to calculate implicit prices along the lines set out in Section 3.6, and compare these with the consumer prices in nearby urban centers. The difference between both measures an implicit trade and transportation margin. Clearly, this margin should increase with the distance to the main consuming areas. We show results for rice and wheat, the major staples, by means of a price map computed through kernel density regression.



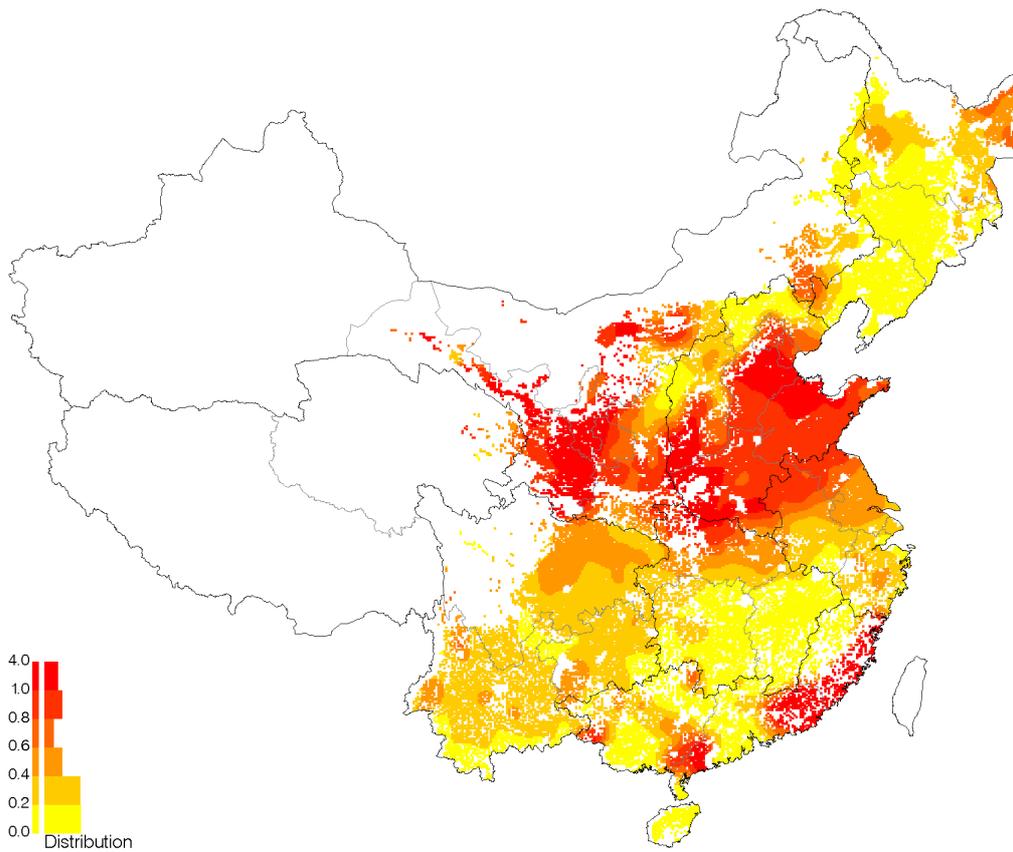
**Figure 5. Shadow price of rice (Yuan/kg)**

Figure 5 displays the implicit price of rice for the main rice producing provinces. Figure 6 shows the population density in 100 persons per km<sup>2</sup>. It appears that the farm gate price of rice is in general higher in areas with a high population density. This holds especially for the relatively urbanized areas in the Southern provinces Guangdong, Guangxi and Hainan. Also the Red Basin area in Sichuan and the Dongbei Pingyuan Plains stretching from South to North in the three North-Eastern provinces exhibit rising prices closer to consuming areas. Thus, the figures indicate that our (purely quantity based) estimation results in a positive trade and transportation margin.

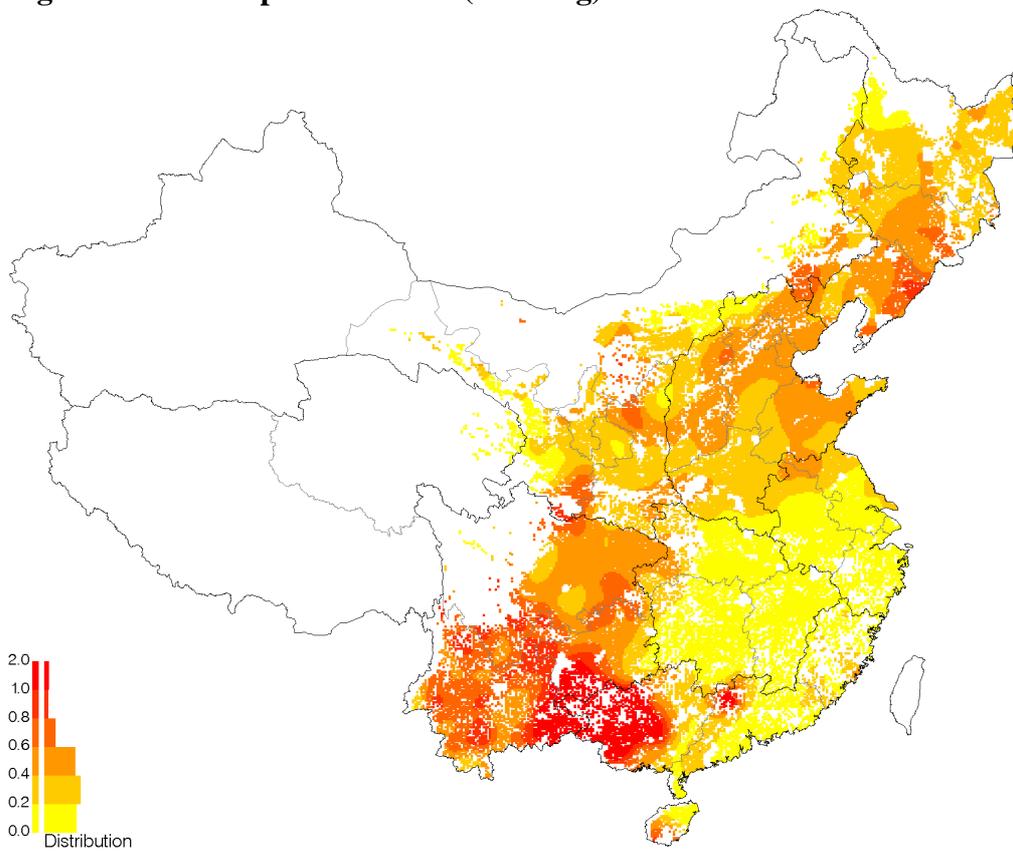
The implicit prices of the two other major crops, wheat and maize, for the relevant producing areas are shown in Figures 7 and 8, respectively. The picture also shows prices rising as one comes nearer to densely populated areas. Wheat has an outlier in the South region, resulting in high farm gate price. Note that there is no wheat in the plains of the North-East where the conditions are more favorable for maize, which is grown on more than 50 percent of the area.



**Figure 6. Population density (persons/km<sup>2</sup>)**



**Figure 7. Shadow price of wheat (Yuan/kg)**



**Figure 8. Shadow price of maize (Yuan/kg)**

**Table 11. Price comparison of original and shadow prices for the major crops**

Region	Rice		Wheat		Maize	
	Original	Shadow	Original	Shadow	Original	Shadow
North			0.66	1.00	0.53	0.42
North-East	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				
South-West	0.55	0.59	0.57	0.42	0.55	0.67
North-West/Plateau	0.71	0.61	0.64	0.84	0.46	0.39

Source: Original prices (SBB, 1992b)

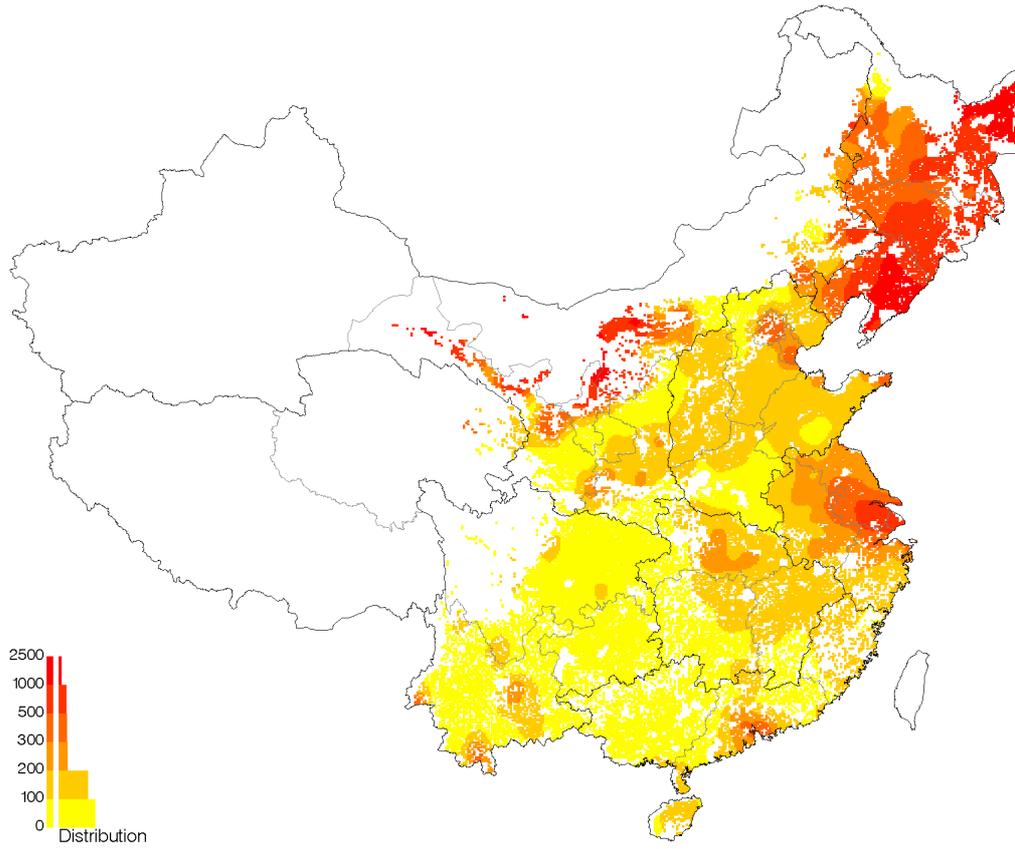
Shadow prices using (3.13) (regional average is weighted with production)

Table 11 compares observed farm gate prices and implicit prices at regional level for rice, wheat and maize. The implicit prices are weighted with the county production. In the main producing regions, they are seen to fluctuate around the farm gate levels in the original statistics. As mentioned earlier, these recorded farm gate prices are a quantity-weighted mean of quota prices, negotiated prices, and free-market prices. They will tend to lie below marginal productivity and hence below implicit free market prices.

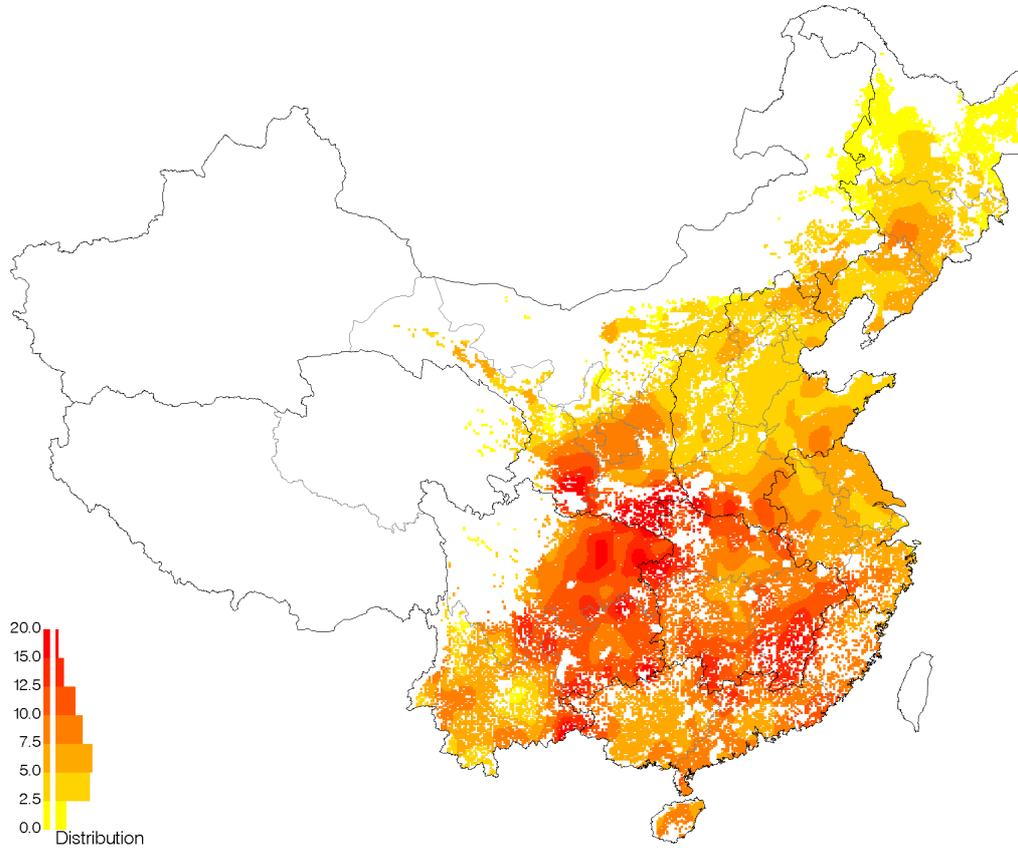
We conclude that the differences between the observed market prices and the imputed farm gate prices leave positive margins that follow a plausible geographical pattern. This suggests that by keeping these margins exogenous to the farm model in a county, it becomes possible to reproduce the main properties of crop farming in China by means of a static profit maximizing model.

## 5.5 Marginal productivity

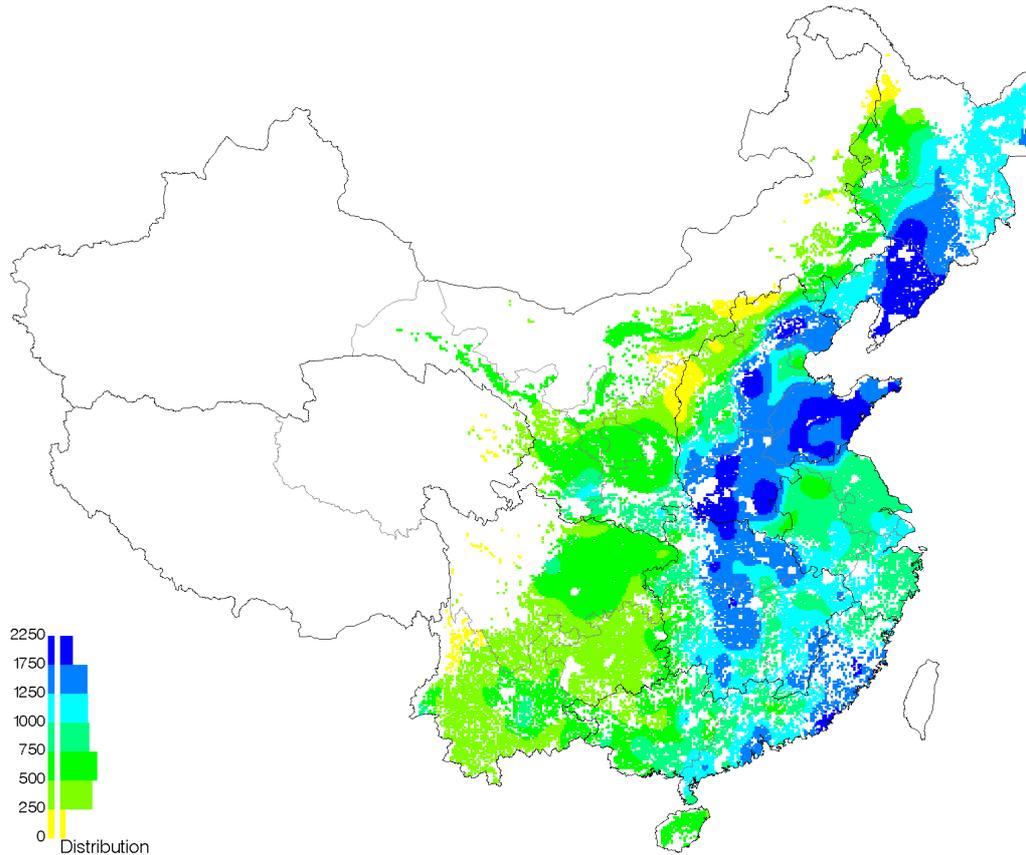
Figures 9 and 10 present maps for the marginal productivity of labor and machinery. It appears that the marginal productivity of agricultural labor is usually higher in the neighborhood of large urban areas: Hong Kong, Shanghai, Beijing, Tianjin and the delta of Liaoning. The figures also show that in the Southern regions (South-West, Central and South) the marginal productivity for machinery is higher and that it is lower for labor.



**Figure 9. Marginal productive of labor (Yuan/person)**



**Figure 10. Marginal productivity of machinery (1000 Yuan/10kW)**



**Figure 11. Marginal productivity of irrigated land (Yuan/ha)**

Figure 11 maps the marginal value of irrigated land – which by construction stands in fixed, region-specific proportion to the marginal productivity of rain-fed land. Along the coastal zone and in the North-East, it follows the pattern of population density quite closely but land inwards the relationship is loose. Although marginal productivity is somewhat higher in the Red Basin area in Sichuan than in the surrounding mountainous area, its level lies substantially below comparable urban areas along the coast.

**Table 12. Input cost in Yuan per laborer**

Region	North	North-East	East	Central	South	South-West	North-West / Plateau
Chemical fertilizer	631	425	947	683	897	498	350
Organic fertilizer	176	16	301	213	456	249	66
Machinery	531	547	517	562	487	257	496
Wage and land	813	2321	673	580	631	287	666
Total costs	2151	3309	2438	2038	2471	1291	1578

At regional level, the average implicit costs (and returns) per laborer for land and wage are lowest in Central and South-West (see Table 12). In the South-West region, an average laborer earned in 1990 an income of 287 Yuan. For the coastal regions South, East and North the earnings for a crop laborer range from 631 Yuan to 813 Yuan on average. This pattern is in line with the observed out-migration to the coastal provinces during the last decade. The marginal productivities of labor and land are highest in the northern provinces.

## **6. Conclusions**

The paper has reported on the specification and estimation of a spatially explicit transformation function for crop production in China, and indicated that the implicit prices associated to this function seem compatible with static profit maximization at county level, at prices that correct for the distance from the main consuming areas. The next step is to conduct scenario simulations with such a profit-maximizing model, after inclusion of livestock production and feed demand equation. Then, we will confront these with consumer demand and balance of payment restrictions, and the final step will be to incorporate investment into irrigation and solve an inter-temporal welfare model.

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## Appendix I:

### 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:

$$Q_\ell(Y, M; \alpha_0, \alpha, \mu) = C_\ell G_\ell(V, A, \bar{y}(x); \theta, \rho, \beta, \gamma, \delta),$$

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

$$Q_\ell = \left( 1 + \sum_m \mu_m M_{\ell m} \right) \left( \sum_c (\alpha_c Y_{\ell c})^{\alpha_0} \right)^{1/\alpha_0}, \quad (\text{I.1})$$

and on the input side  $C_\ell$  is the sum of cropping zone constants

$$C_\ell = \sum_z \zeta_z Z_{\ell z},$$

while  $G_\ell$  is the generalised Mitscherlich-Baule function:

$$G_\ell = \prod_j f(V_\ell, A_\ell; \beta, \gamma, \delta, \rho)^{\theta_j} N(A_\ell, \bar{y}_\ell(x); \delta) \quad (\text{I.2})$$

with

$$f_{\ell j} = 1 - \exp(-\beta_j - w(V_\ell/H_\ell))$$

$$w_{\ell j} = \left( \sum_{k \in j} \gamma_k (V_{k\ell} / H_\ell)^{\rho_j} \right)^{1/\rho_j}$$

$$H_\ell = \sum_s \delta_s A_{\ell s} \quad \text{and}$$

$$N_\ell = H_\ell \bar{y}_\ell$$

Index  $\ell$  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 by each of seven regions.

## Numerical implementation of the estimation procedure

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

1. Generation of the initial quantities  $\tilde{q}_\ell = \tilde{Q}_\ell / H_\ell$  as data for the separate estimation of the input and the output function. Calculation of  $\bar{y}_\ell = \bar{Y}_\ell / H_\ell$ .
2. Iterative estimation of parameters of the input function  $\tilde{q}_\ell = C_\ell \cdot G_\ell / H_\ell + \varepsilon_1$  by linear regression using a first-order Taylor expansion of the function, which is adjusted until convergence. This provides good initial estimates for 3.
3. Further estimation of the parameters of the input function in the original nonlinear form.
4. Estimation of parameters of the output function  $\tilde{q}_\ell = Q_\ell / H_\ell + \varepsilon_2$  in the nonlinear form, for fixed substitution parameter  $\alpha_0$ .
5. Update the quantity index  $\tilde{q}_\ell$  and go to Step 3 until convergence.

Thus, Steps 1-2 constitute the initialization and Steps 3-5 the actual estimation. We note that a free nonlinear regression would do without separate data for the quantity index, but attempts to relax this restriction causes convergence problems in the estimation. 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 also by assessing the resulting change in the other parameters in the calculation of the likelihood ratios (which performs new rounds of least squares while 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  $\tilde{Q}_\ell$  is calculated based on the available provincial prices  $P_{rc}$ , the national prices  $P_c$  and the county-level crop outputs  $Y_{\ell c}$ . 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

$$P_r^i = \frac{\sum_c P_{rc} Y_{rc}}{\sum_c P_c Y_{rc}}$$

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  $\ell$  in province  $r$ , yielding a country-level output index  $\tilde{Q}_\ell$ .

$$\tilde{Q}_\ell = \sum_c Y_{\ell c} P_{\ell c} / P_\ell^i$$

*Step 2.* The Taylor expansion uses two matrices  $e$  and  $e_p$  of dimension  $z \times \psi$ . Let subscript  $p$  denote the results of the previous iteration. Using the definitions of (I.1) and (I.2), the sum of squared disturbances  $e_\ell(z; \psi)$  can be written as:

$$e_\ell(z; \psi) = Q_\ell - C_\ell(Z_{\ell z}; \zeta_z)G(V_{\ell j}, A_{\ell s}, \bar{y}_{\ell s}; \theta_j, \beta_j, \rho_j, \gamma_k)/H_\ell \quad (\text{I.3})$$

and the derivatives are:

a) partial derivative with respect to  $\zeta_z$ :

$$\frac{\partial e_\ell}{\partial \zeta_z} = -Z_{\ell z} G_\ell / H_\ell \quad (\text{I.4a})$$

b) partial derivative with respect to  $\theta_j$ :

$$\frac{\partial e_\ell}{\partial \theta_j} = -\log f_{\ell j} C_\ell G_\ell / H_\ell \quad (\text{I.4b})$$

c) partial derivative with respect to  $\beta_j$ :

$$\frac{\partial e_\ell}{\partial \beta_j} = -\theta_j \frac{1 - f_{\ell j}}{f_{\ell j}} C_\ell G_\ell / H_\ell \quad (\text{I.4c})$$

d) partial derivative with respect to  $\rho_j$ :

$$\frac{\partial e_\ell}{\partial \rho_j} = \frac{-\theta_j w_{\ell j} (1-f_{\ell j})}{\rho_j f_{\ell j}} \left( \frac{\log w_{\ell j}^{\rho_j}}{\rho_j} - \frac{\sum_{k \in j} (\gamma_k v_{\ell k}^{\rho_j} \log v_{\ell k})}{w_{\ell j}^{\rho_j}} \right) C_\ell G_\ell / H_\ell \quad (\text{I.4d})$$

with  $v_{\ell k} = V_{\ell k} / H_\ell$

e) partial derivative with respect to  $\gamma_k, k \in j$ :

$$\frac{\partial e_\ell}{\partial \gamma_j} = -\theta_j \frac{1-f_{\ell j}}{f_{\ell j}} \frac{1}{\rho_j} w_{\ell j}^{1-\rho_j} v_{\ell j}^{\rho_j} C_\ell G_\ell / H_\ell \quad (\text{I.4e})$$

*Step 3.* To avoid parameters drifting away in course of the estimation, the parameters  $\zeta$ ,  $\theta$ ,  $\rho$  and  $\eta$  are estimated keeping the others fixed, and next the parameters  $\beta$  and  $\gamma$  are estimated keeping  $\zeta$ ,  $\theta$ ,  $\rho$  and  $\eta$  fixed. The parameters are updated until convergence is reached. The update procedure of the parameters and convergence level are the same as in Step 2.

*Step 4.* The parameter  $\alpha_0$  is estimated by scanning over the interval [1.5, 2].

*Step 5.* Convergence is reached when two full rounds lead to less than 0.1 percent change of the sum of squares of  $\left( \hat{Q}_\ell / H_\ell - \hat{C}_\ell \hat{G}_\ell / H_\ell \right)$ .

The entire estimation procedure was implemented in GAMS\* (Brooke et al., 1992). 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 transfer 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".

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\* The acronym 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 II

### Output elasticities of input k and land input s, and of crop c

Output elasticity with respect to input  $V_{\ell k}$  :

$$\frac{\partial G_{\ell}}{\partial V_{\ell k}} \frac{V_{\ell k}}{G_{\ell}} = \frac{1-f_{\ell j}}{f_{\ell j}} \theta_j \gamma_k w_{\ell j}^{1-p_j} \left( \frac{V_{\ell k}}{H_{\ell}} \right)^{p_j} \quad (\text{II.1})$$

Output elasticity with respect to land input of type  $A_{\ell s}$  :

$$\frac{\partial G_{\ell}}{\partial A_{\ell s}} \frac{A_{\ell s}}{G_{\ell}} = \frac{\delta_s A_{\ell s}}{H_{\ell}} \left( 1 - \sum_j \left( \theta_j \frac{1-f_{\ell j}}{f_{\ell j}} w_{\ell j} \right) \right) \quad (\text{II.2})$$

Output elasticity with respect to crop  $Y_{\ell c}$  :

$$\frac{\partial Q_{\ell}}{\partial Y_{\ell c}} \frac{Y_{\ell c}}{Q_{\ell}} = \frac{(\alpha_c Y_{\ell c})^{\alpha_0}}{\sum_c (\alpha_c Y_{\ell c})^{\alpha_0}} \quad (\text{II.3})$$