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ARTICLE

Economic Effects of Drought on Agriculture in North China

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Abstract In the past three decades, global agriculture losses have continuously grown due to increasingly severe droughts. Compared with direct economic effects, there are great difficulties in evaluating the indirect economic effects of drought, which has severely lagged behind the urgent information needs for decision making. This study tries to solve the perplexity in the evaluation of the effects of drought on the price fluctuation of agricultural products by building a partial equilibrium model that describes the balancing process of supply and demand quantitatively. Using this model, a scenario analysis is applied to evaluate the price fluctuation of agricultural products caused by drought in North China. The results indicate that there is no major impact of drought on the market prices of eight major agricultural products. Even with the occurrence of a severe drought in North China, market prices of agricultural products will rise no more than 3.59 percent, which is less than the normal market price fluctuations of China's agricultural products. This study provides a tool for evaluating indirect economic effects of drought. The results of our case study could support decision making for China's food market regulation.

Keywords drought, equilibrium model, indirect economic effects, North China, prices of agricultural products

1 Introduction

As one of the main constraints of the world's agricultural development, drought has raised great concerns. For nearly a half century, especially after the 1980s, the world's arid areas have continuously expanded along with climatic warming and drying. This development seriously threatens global food security (Shi 2005; Deng et al. 2011; Liu and Yang 2012). As a major agricultural country, China, especially Northwest and North China, suffers serious drought every year. In the wake of significant precipitation reduction in the northern region for almost 50 years, drought has gradually become the meteorological disaster of widest influence and highest frequency (Xu et al. 2006; Yin, Yin, and Xu 2011). In most arid and semiarid regions of China, drought has caused serious impacts on agriculture and livestock production systems and resulted in deterioration of the ecological environment. The heavy agricultural losses caused by drought have become one of the major obstacles to China's regional development. According to the *2nd National Assessment Report on Climate Change* (Ministry of Science and Technology of the People's Republic of China, Chinese Academy of Sciences, and China Meteorological Administration 2011), the climatic warming and drying tendency will be increasingly stronger in North China. Drought will occur more frequently and be more severe in China in the future.

Effects of natural disasters, including drought, on regional economy can be divided into direct and indirect effects (Cheng et al. 2011; Yin, Yin, and Xu 2011). Direct effects are characterized by abruptness and refer to direct physical damage caused by natural disasters on production factors and products. Indirect effects are derivatives of direct effects and refer to impacts of output and supply dislocation between economic sectors caused by natural disasters. Indirect effects of drought are always more serious than direct effects because agriculture is the foundation of economy and is always hit first by drought (Wu et al. 2009).

Direct economic effects of drought can be calculated by accumulating the maintenance costs and reset and idle costs of movable and immovable property. A relatively complete assessment system has been established for evaluating direct economic effects of drought in China (Zhang and Mei 1999; Wu et al. 2009). Indirect economic effects of drought are the long-term results of direct economic effects combined with a series of production interruptions, consumption declines, and market fluctuations. Given the complexity of these economic and social links, the assessment of the indirect economic effects of drought is difficult because of the lack of theoretical and methodological foundations (Cochrane 1997). The Computable General Equilibrium (CGE) model is one of the feasible methods that can be used to evaluate indirect economic effects of drought. It is a simulation that combines the abstract general equilibrium structure with realistic economic data to calculate the levels of supply, demand, and price that support equilibrium across a specified set of markets (Wing 2004). As standard tools of empirical analysis, CGE models simultaneously determine changes in quantities

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of goods supplied and demanded, and their prices, in an aggregated multisectoral and multiagent setup. They have been used for the analysis of tax reform, income distribution, global warming, agricultural management, sporting events, and even the analysis of the impact of the intifada demonstrations (Mitra-Kahn 2008). Some studies have also used CGE models to evaluate the economic effects of natural disasters. For example, Cochrane (1984) used a CGE model to estimate the economic effects of natural disasters and found that elasticity of substitution, marginal utility, and regional trade are the key constraint conditions of magnitude of regional economic effects of natural disasters. Wittner, McKirdy, and Wilson (2005) used a dynamic regional CGE model in a simulation modeling exercise on the effects of a disease or pest outbreak. However, due to the requirements for high precision parameters and the difficulties in obtaining a Social Accounting Matrix (SAM), the application of CGE models in the estimation of economic effects of drought is greatly limited.

Partial equilibrium model, where the clearance on the market of some specific goods is obtained independently from prices and quantities demanded and supplies in other markets, presents itself as an alternative tool (Roningen 1997). A partial equilibrium model not only has the same advantage in describing the price and market as a CGE model, but also can concentrate the research subjects in several key sectors we are especially concerned about. Partial equilibrium models have been used in many fields including energy security, tariffs, and demand for production factor inputs and climate changes (Tromborg, Bolkesjo, and Solberg 2007; Kamiński and KudeŁko 2010; Takahashi 2012). Partial equilibrium models are characterized by stronger operability compared with CGE models because of the reduced difficulty of data acquisition for the parameters. Therefore, in this study, we choose the partial equilibrium modeling framework to model the indirect economic effects of drought.

The overall goals of this research are to build a partial equilibrium model, the Indirect Agricultural Economic Effects Evaluation (IAEEE) model, for evaluating the indirect economic effects of drought on agriculture, and to demonstrate, through a case study of drought in North China, that such a model is useful in providing information for decision making in improving food security. In the next section we will provide more details on drought in North China. The IAEEE model and data will then be introduced and the scenarios and results are presented and discussed.

2 Drought in North China

Traditionally, North China includes the municipalities of Beijing and Tianjin, the provinces of Hebei and Shanxi, and the Inner Mongolia Autonomous Region. In this study, however, we define North China as an area that also includes the adjoining Shandong and Henan Provinces, because of the high importance of agriculture and the frequent drought occurrences in these two provinces. Thus defined, North China accounts for one fifth of the total land area and one-third of the cultivated land of China (Figure 1). Shandong, Henan, and Hebei, with rich cultivated land resources and good light and heat conditions, are important agroecological zones and grain, cotton, and oil producing areas (Feng 1985; Ding, Xiao, and Song 1992; Li 1999; Gao 2003), and Inner Mongolia is one of the main animal husbandry areas in China. While North China is the most important commodity grain production area in China, it is also one of China's most drought-afflicted regions (Wang and Zhai 2003; Ma 2007; Ruan, Liu, and Li 2008). Over the years, drought, especially spring drought, has been a major factor that has affected agricultural production in North China (Lu and Huang 2004; Liu 2009). In particular, the severe droughts in the 1995–2007 period caused huge losses in agriculture in this region (Figure 2).

3 Model and Data

This section starts with the partial equilibrium modeling framework for the indirect economic effects of drought. Based on the framework, the economic behaviors relating to the agricultural industry are described in detail. The evaluation is implemented using the statistical data of national scale, which is introduced at the end of this section.

3.1 Indirect Agricultural Economic Effects Evaluation Model for Drought

We built an Indirect Agricultural Economic Effects Evaluation (IAEEE) model for drought based on the partial equilibrium modeling framework. The model mainly depicts economic behaviors such as agricultural production, consumption, trade, saving, and taxes of agricultural sectors as well as households and government. These economic behaviors in the model can be divided into five modules—producer behavior, household behavior, government behavior, commodity trade, and equilibrium process according to their economic roles. There are close economic relationships among the five modules (Figure 3). The producer behavior module describes agricultural production and agricultural commodity supply. Parts of the domestic agricultural products are exported to other countries, and the rest are sold in domestic commodity markets. Commodity export and import as well as domestic commodity circulation are described by the commodity trade module. We assume that the import commodities and domestic products are imperfect substitutes. The household behavior module describes factor supply, household consumption, and household saving behaviors. The government behavior module describes taxation, government consumption, and government saving behaviors. Household and government savings are assumed completely transformed into investment in the IAEEE model. The equilibrium process module provides for equilibrium of domestic commodity

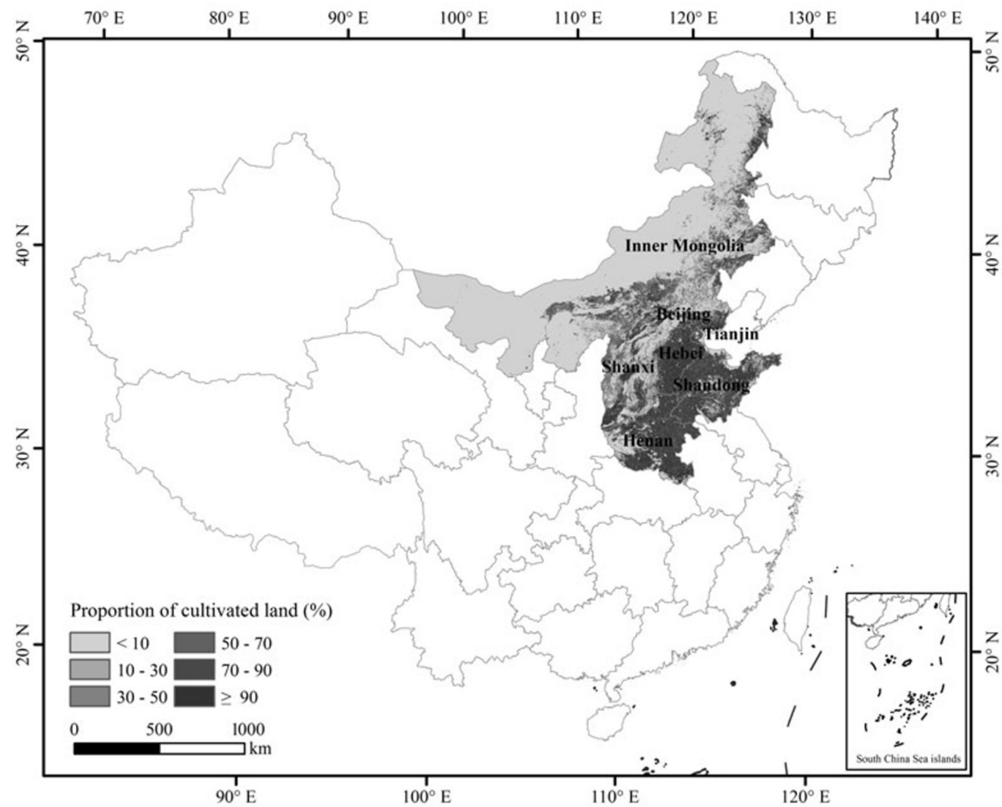

Figure 1. The North China Provinces and Municipalities

Note: Proportion of cultivated area is the proportion of cultivated land in each 1 km×1 km grid. The initial data of cultivated area are derived from Landsat TM/ETM image dataset (Liu, Zhang, and Zhuang 2003).

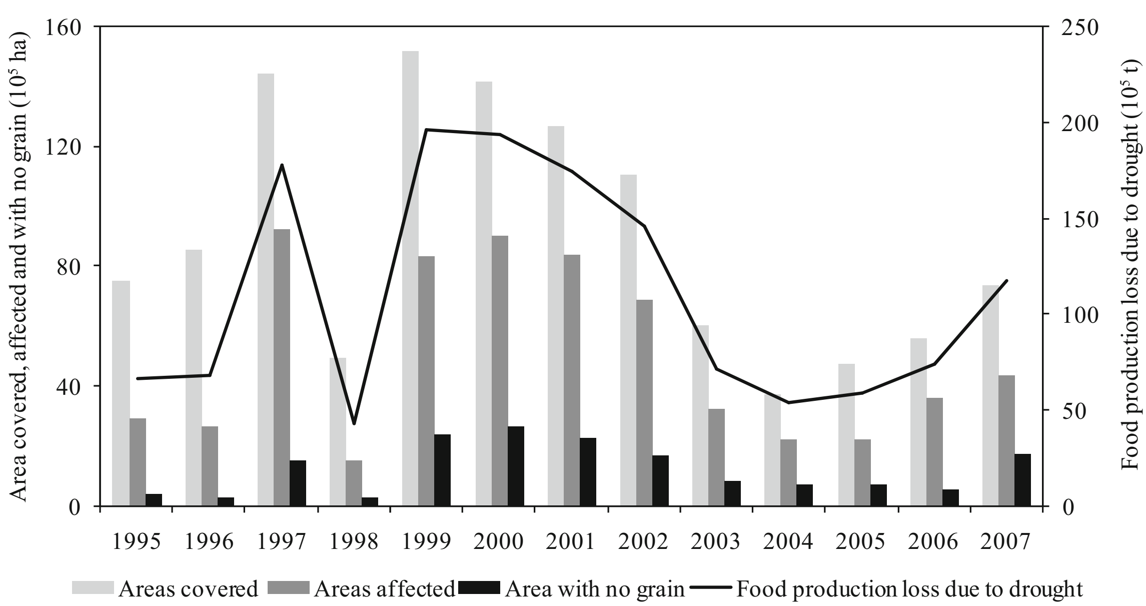

Figure 2. Drought impact on agriculture in North China, 1995–2007

Sources: *China Statistical Yearbook* (National Bureau of Statistics of China 1996–2008) and *China Agricultural Yearbook* (Editorial Committee of China Agricultural Yearbook 1996–2008), summarized by the authors.

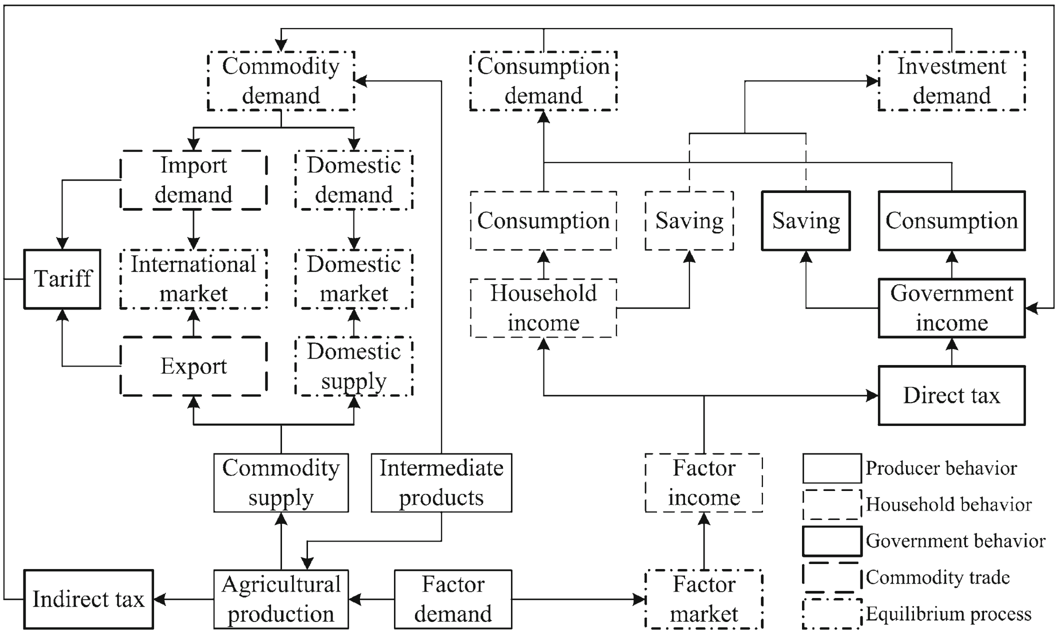

Figure 3. Economic relationship among modules of the Indirect Agricultural Economic Effects Evaluation (IAEEE) model

market, factor market, and trade balance. The producer behaviors, household behaviors, government behaviors, commodity trades, and equilibrium processes related to other commodities besides agricultural products are exogenously fixed in the model.

3.1.1 Producer Behavior

Producers carry out their agricultural and livestock production activities under certain conditions of production technology to ultimately achieve the objective of maximizing profit. And the behavior of producers can be expressed by solving an extreme problem of the dual function:

$$\max_{Z_j, F_{hj}} \pi_j = P_j^s \cdot Z_j - \sum\nolimits_i P_i^d \cdot X_{ij} - \sum\nolimits_h r_h \cdot F_{hj} \quad \text{Eq. 1}$$

$$\text{s.t. } Z_j = \min\left\{ (1-c_1) X_{1j} / ax_{1j}, \; (1-c_2) X_{2j} / ax_{2j}, \ldots, b_j \prod\nolimits_h F_{hj}^{\beta_{hj}} / ay_j \right\} \quad \text{Eq. 2}$$

where π_j represents eventual profit of the jth agricultural and livestock production; P_j^s is the supply price of the jth agricultural and livestock product; Z_j is the eventual output of the jth agricultural and livestock product; P_i^d denotes the price of the ith intermediate input product; r_h is the price of factor h; F_{hj} is the amount of factor h input in the production of commodity j; X_{ij} represents the amount of intermediate input i consumed in the production of commodity j; c_i denotes the disaster loss coefficient of intermediate input i; ax_{ij} and ay_j represent the consumption coefficient of intermediate inputs and intermediate products, respectively; b_j is a scaling parameter; and β_{hj} is a share parameter.

Besides local sales, domestic agricultural and livestock products are also exported to other regions and countries. Conversely, parts of agricultural and livestock products sold in China are imported from other regions and countries. According to the profit-maximization assumption, the market shares of imported products and the domestically produced and sold products can be calculated by solving the following extreme problem:

$$\max_{M_i, D_i} \varpi_i = P_i^s \cdot Q_i - \left[Pd_i \cdot D_i + Pm_i \cdot (1 + \tau m_i) \cdot M_i \right] \quad \text{Eq. 3}$$

$$\text{s.t. } Q_i = \gamma_i \left(\delta m_i M_i^{\eta_i} + \delta d_i D_i^{\eta_i} \right)^{1/\eta_i} \quad \text{Eq. 4}$$

where Q_i represents the amount of integrated commodity i domestically sold; Pd_i and Pm_i denote the prices of domestic commodity i and imported commodity i, respectively; D_i and M_i denote the amounts of domestically produced and sold commodity i and imported commodity i, respectively; τm_i is the import tariff rate of commodity i; γ_i is the scaling parameter of the Armington function; δm_i and δd_i are share parameters of the Armington function, $\delta m_i + \delta d_i = 1$; and η_i is the elasticity of substitution between domestically produced and imported commodity i.

Similarly, the market share of agricultural products for exports and domestic sale can be expressed as:

$$\max_{E_i, D_i} \omega_i = P_i^s \cdot Z_i - \left[Pd_i \cdot D_i + Pe_i \cdot (1 - im_i) \cdot E_i \right] \quad \text{Eq. 5}$$

$$\text{s.t. } Z_i = \theta_i \left(\xi e_i E_i^{\Phi_i} + \xi d_i D_i^{\Phi_i} \right)^{1/\Phi_i} \quad \text{Eq. 6}$$

where Pe_i denotes the price of exported commodity i; E_i represents the amount of exported commodity i; im_i is the rate

of export subsidies of commodity i; Φ_i is the scale parameter of domestically produced and exported commodity i; and ξe_i and ξd_i are the share parameters, $\xi e_i + \xi d_i = 1$.

3.1.2 Household Behavior

Household behavior refers to the decision-making process of households on consumption and saving under income constraint. Households' income mainly comes from various factor returns deducting direct taxes. The ultimate goal of household behavior is to achieve utility maximization by optimizing their consumption of different commodities. This process can be expressed by solving the following extreme problem of the dual function:

$$\max_{XP_i} UU^H = \prod_i \left[(1-c_i) Xp_i \right]^{\alpha_i} \qquad \text{Eq. 7}$$

$$\text{s.t.} \sum_i P_i^d \cdot XP_i = \sum_h (1 - ss - \tau d) r_h \cdot FF_h \qquad \text{Eq. 8}$$

where Xp_i denotes household demand for commodity i; α_i represents the share of household income (except for savings) for purchasing commodity i; FF_h is the amounts of factor h supplied for production; ss is the household savings rate; and τd is the direct tax rate.

3.1.3 Government Behavior

Similar to household behavior, government behavior can also be regarded as a utility maximization problem under government revenue constraint. It can be expressed as:

$$\max_{Xg_i} UU^G = \prod_i \left[(1-c_i) Xg_i \right]^{\mu_i} \qquad \text{Eq. 9}$$

$$\text{s.t.} \sum_i P_i^d \cdot Xg_i = (1 - ssg)\Big(\tau d \cdot \sum_h r_h \cdot FF_h + \sum_j \tau_j \cdot P_j^s \cdot Z_j + \tau m_i \cdot Pm_i \cdot M_i - im_i \cdot Pe_i \cdot E_i\Big) \qquad \text{Eq. 10}$$

where Xg_i denotes government demand for commodity i; μ_i is the share of government revenue for purchasing commodity i; τ_j and τm_j represent the indirect tax rate and tariff rate, respectively; and ssg represents the government savings rate.

3.1.4 Commodity Trade

In this model, we assume that the difficulty of trading between regions (provinces) is proportionally related to their distance, and the prices of exported and imported commodities are determined by the commodity price in the international market and exchange rate.

$$V(r,d)/V(*,d) \propto \sqrt{V(r,*)}/D(r,d)^k, \quad r \neq d \qquad \text{Eq. 11}$$

$$Pm_i = \varepsilon Pwm_i \qquad \text{Eq. 12}$$

$$Pe_i = \varepsilon Pwe_i \qquad \text{Eq. 13}$$

where k is the convenience degree of trade between the provinces; $V(r, d)$ denotes the value flow from province r to province d; and $D(r, d)$ denotes the distance between provinces r and d; Pwm_i is the import price of commodity i (foreign currency); Pwe_i is the export price of commodity i (foreign currency); and ε is the exchange rate.

3.1.5 Equilibrium Process

Market equilibrium includes commodity market equilibrium, factor market equilibrium, trade balance, and savings and investment balance.

$$\begin{cases} Q_i = (1-c_i)\left(\sum_j X_{ij} + Xp_i + Xg_i + Xv_i\right) \\ (1-a_h) FF_h = \sum_j F_{hj} \\ \sum_i Pe_i \cdot (1 - im_i) \cdot E_i + Sf = \sum_i Pm_i \cdot (1 + \tau m_i) \cdot M_i \\ \sum_i P_i^d \cdot Xv_i = ss \cdot \sum_h r_h \cdot FF_h + \\ ssg \left(\tau d \cdot \sum_h r_h \cdot FF_h + \sum_j \begin{matrix} \tau_j \cdot P_j^s \cdot Z_j + \tau m_i \cdot Pm_i \cdot M_i \\ - im_i \cdot Pe_i \cdot E_i \end{matrix} \right) + Sf \end{cases} \qquad \text{Eq. 14}$$

When a drought occurs, agricultural production suffers the shock and the outputs of agriculture reduce, which leads to the change of other economic variables such as consumption and investment, until a new equilibrium is achieved.

3.2 Data

We constructed a database for the IAEEE model just like other computable equilibrium models such as The Enormous Regional Model (TERM), the Global Trade Analysis Project (GTAP) model, and the EUropean CAR emissions (EUCARS) model (Hertel 1997; Denis and Koopman 1998; Horridge, Madden, and Wittwer 2005). The database includes four kinds of crop products—rice, wheat, maize, and legumes; four kinds of animal products—pork, beef, eggs, and milk products; three kinds of production factors—capital, labor, and land; as well as household, government, and foreign trade. We have 199 variables involved in the IAEEE model (Table 1). The data used in the IAEEE model are mainly from the 2008 national statistical dataset. Specifically, data of intermediate and factor inputs of agricultural production are from the rural survey dataset of the National Bureau of Statistics of China; data for agricultural products consumption, government procurement, import, and export are from the national statistical yearbook; and drought data are provided by the Ministry of Science and Technology and China National Commission for Disaster Reduction.

The parameters, such as share parameters, input shares, and tax rates, of the IAEEE model are calculated using the

Table 1. Variables involved in the study

Variable	Meaning	Index Size
Xp_i	Household demand for agricultural product *i*	8
Xg_i	Government demand for agricultural product *i*	8
Xv_i	Investment demand for agricultural product *i*	8
F_{hj}	Amount of factor *h* input in the production process of agricultural product *j*	24
Y_j	Value added in the production process of agricultural product *j*	8
X_{ij}	Demand for intermediate input *i* in the production process of agricultural product *j*	64
Z_j	Eventual output of agricultural product *j*	8
FF_h	Amount of factor *h*	3
E_i	Export volume of agricultural product *i*	8
M_i	Import volume of agricultural product *i*	8
Td	Direct tax	1
Q_i	Supply of integrated commodity *i*	8
S	Total household saving	1
Sg	Total government saving	1
Sf	Total foreign saving	1
Pwe_i	Export price of commodity *i* (Foreign currency)	8
Pwm_i	Import price of commodity *i* (Foreign currency)	8
T_j	Indirect tax	8
Tm_j	Tariff	8
Im_j	Export subsidy	8

Note: Agricultural products include rice, wheat, maize, legumes, pork, beef, eggs, and milk products and are indexed by *i* and *j*. Production factors include capital, labor, and land and are indexed by *h*.

database we built. Finally, we obtain 199 equations with 199 variables. The General Algebraic Modeling System (GAMS) is used to solve these equations. Through scenario analysis, we can evaluate the market price change (illustrated by the market price index) of agricultural products caused by drought in North China.

4 Drought-Induced Price Fluctuations of Agricultural Products

In this section, three drought scenarios are designed to provide more useful information for decision making in improving food security. The simulation results of these three drought scenarios' impact on national market prices of agricultural products are presented. The comparison between the prices of different agricultural products and different drought scenarios are also presented.

4.1 Scenarios

The direct impact of drought on agriculture is reduction or loss of harvest. Production reduction can reflect the degree of regional drought. According to the statistical data of 1995–2007, rice production losses caused by droughts in North China were 0.13–0.43 percent of the total national output of rice; wheat production losses caused by droughts in North China were 1.88–9.60 percent of the total national output of wheat; and the droughts in North China caused 1.41–7.74 percent and 0.82–3.84 percent losses of the total national output of maize and legumes, respectively (Figure 4).

Three scenarios—mild drought, moderate drought, and severe drought—were designed to analyze the impact of drought in North China on prices of agricultural products. Under the mild drought scenario, we suppose that the proportions of national grain production losses due to drought in North China are at the lower end of the 1995–2007 values; the proportions of national grain production losses caused by drought in North China are assumed to be the mean 1995–2007 values under the moderate drought scenario; and under the severe drought scenario, the proportions of national grain production losses caused by drought in North China are assumed to be the peak values from 1995–2007 (Table 2). For example, the proportions of wheat production losses are assumed to be 1.88 percent under the mild drought scenario, 5.19 percent under the moderate drought scenario, and 9.60 percent under the severe drought scenario. The disaster loss coefficients of intermediate inputs (c_i) in the IAEEE model are assigned the values of the proportion of grain production losses of the three scenarios. Consequently, we can simulate the effects of drought of different severities on national market prices of agricultural products.

4.2 Results

Applying the IAEEE model for drought, we evaluate the effects of drought in North China on national market prices of agricultural products under the three designated scenarios—mild drought, moderate drought, and severe drought. The results indicate that the price fluctuations of agricultural products differ from scenario to scenario. Overall, the average price rise of agricultural products is the largest under the

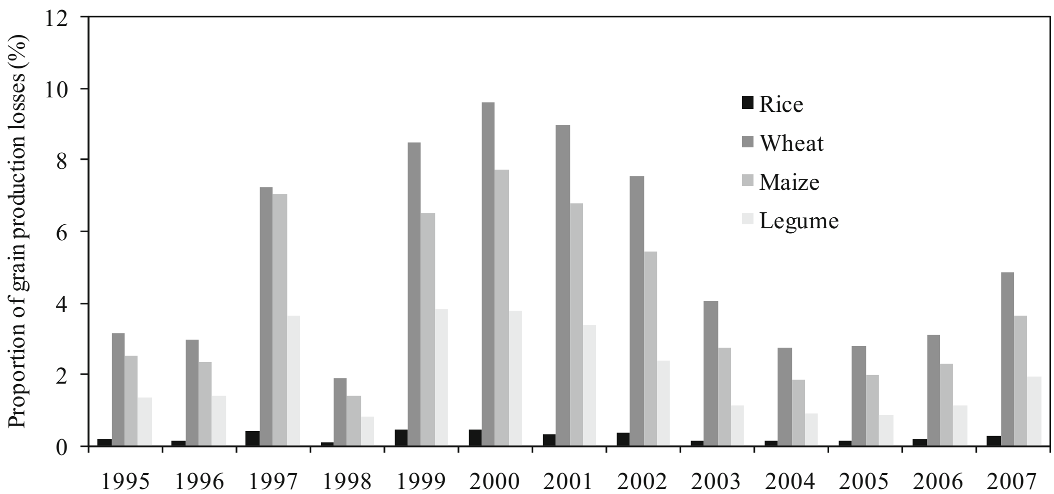

Figure 4. Proportion of grain production losses in China caused by droughts in North China, 1995–2007
Sources: *China Statistical Yearbook* (National Bureau of Statistics of China 1996–2008) and *China Agricultural Yearbook* (Editorial Committee of China Agricultural Yearbook 1996–2008), summarized by the authors.

severe drought scenario and the least under the mild drought scenario.

Compared with a drought-free situation, the prices of rice, wheat, and beef rise by 0.67 percent, the prices of maize, pork, eggs, and milk products rise by 0.56 percent, and the price of legumes rises by 0.57 percent under the mild drought scenario (Table 3). These results indicate that, though North China is not the main rice producing area and the impact of drought in North China on the national rice outputs is low, as a main substitute of wheat, the demand and price of rice increase when the outputs of wheat decline. Compared with wheat, the price rises of legumes and maize are smaller. This is mainly due to the fact that the proportion of legumes and maize cropping is far less than that of wheat in North China, and the substitutional relationships among these three crops are not strong. The prices of pork, eggs, and milk products correspondingly rise, because maize is the main feed of pigs, chickens, and cows. The price rise of maize leads to the increase of production cost of these three agricultural products. Beef experiences a relatively high price rise because North China, especially Inner Mongolia, plays an important role in supplying beef nationally. Inner Mongolia has the most developed beef cattle industry in China. Consequently, the rise of beef production costs caused by drought has a greater impact on the Chinese beef market.

Under the moderate drought scenario, the prices of maize, pork, eggs, and milk products rise by 1.78–1.79 percent, and the prices of wheat and rice rise by 1.89 percent and 1.78 percent, respectively, compared with the drought-free situation. The rise in the price of beef amounts to 1.91 percent and the price rise of legumes also reaches 1.72 percent under this scenario. The impact of drought on maize production is indirectly transferred to pork, eggs, and milk products, resulting in synchronous price rises of these downstream products. Price changes of wheat and rice also differ under the moderate drought scenario. The rise of beef prices is significantly higher than other agricultural products under the moderate drought scenario compared with the mild drought scenario, which again illustrates the importance of North China for the national beef market.

Table 2. Proportion of grain production losses caused by drought in North China under different scenarios (%)

Crops	Mild Drought Scenario	Moderate Drought Scenario	Severe Drought Scenario
Rice	0.13	0.24	0.43
Wheat	1.88	5.19	9.60
Maize	1.41	4.02	7.74
Legumes	0.82	2.04	3.84

Table 3. Impact of drought in North China on the national price fluctuations of agricultural products

Agricultural Products	Price Index		
	Mild Drought Scenario	Moderate Drought Scenario	Severe Drought Scenario
Rice	100.67	101.78	103.57
Wheat	100.67	101.89	103.56
Maize	100.56	101.79	103.57
Legumes	100.57	101.72	103.56
Pork	100.56	101.78	103.56
Beef	100.67	101.91	103.59
Eggs	100.56	101.79	103.47
Milk products	100.56	101.79	103.46

Note: Market price index of agricultural products is 100 if there is no drought in North China.

Under the severe drought scenario, the prices of rice, wheat, maize, and legumes rise by 3.56–3.57 percent compared with the drought-free situation. The price rise of beef (3.59%) is the highest among the eight products. The prices of eggs and milk products rise by 3.47 percent and 3.46 percent, respectively, the smallest increases among all eight crop and animal products. These results indicate that the demands for eggs and milk products are weakened due to severe drought compared with demand for the five most basic food products including rice, wheat, maize, legumes, and pork, but demand for beef remains strong under this scenario.

5 Conclusions

In this study, we built an IAEEE model based on the partial equilibrium modeling framework for evaluating the indirect economic effects of drought. The production, supply, demand, consumption, and trade of agricultural products including rice, wheat, maize, legumes, pork, beef, eggs, and milk products are quantitatively depicted in the model. When a drought takes place, agricultural production will be disrupted, and the equilibrium between supply and demand of agricultural products will be broken. By comparing the new equilibrium generated by market adjustment mechanisms and the initial equilibrium when there was no drought, we can reveal the economic effects of drought. To examine the practicality of the IAEEE model, we carried out empirical research of estimating the market price fluctuations of agricultural products in China resulting from drought in North China. To obtain robust estimations, three possible drought scenarios—mild drought, moderate drought, and severe drought—in the North China region are designed based on the historical drought loss data. These scenarios cover the whole range of drought situations in North China in the period of 1995–2007.

The evaluation results indicate that drought in North China will lead to an overall rise in prices of agricultural products. Under the moderate drought scenario, prices of agricultural products rise 1.72–1.91 percent compared with when there was no drought. This means that the price rises of agricultural products caused by drought in North China average no more than 2 percent. The evaluation results under the mild and severe drought scenarios show that price rises of agricultural products caused by drought in North China are 0.67 percent at the lowest level and 3.59 percent at the highest level. These two figures provide an interval of price changes caused by drought in North China, which may provide the information of future price changes of agricultural products for decision making.

The IAEEE model for drought built in this study is a partial equilibrium model not involving all socioeconomic sectors. The model is weak when considering the economic behaviors outside agricultural sectors. However, the simplified design of the model is beneficial to revealing the linkages between different agricultural sectors and better at explaining the impact of drought on food prices than existing approaches such as the Proportionality Coefficient method, the Input-Output model, and the Econometric Time-Series model (Percoco 2006; Du et al. 2008).

The case study shows that the IAEEE model is a practical tool for evaluating the economic effects of drought on agriculture. However, due to lack of data, we concentrated our study on droughts that occurred in North China but not the whole country. Because in addition to drought, price fluctuations of agricultural products are affected by many other factors such as industrial demand, cultivated land loss, fertilizer price, as well as trading environment, we are not able to validate our evaluation results. So this study, like many existing studies on indirect economic impacts of disasters, has validation or calibration problems. Examples of such existing studies are Yamano, Kajitani, and Shumuta (2007), Greenberg, Lahr, and Mantell (2007), and Campbell and Knowles (2011). But most scholars agree that it is worthwhile to model indirect economic effects of disasters although model validation is impossible. By quantitatively analyzing economic links more precisely we can evaluate the indirect economic effects of disasters more accurately.

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