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CAN FUTURES TRADING PLAY A ROLE IN CHINA'S LAND ALLOCATION AND FOOD SECURITY POLICY?

by

Jianmin Liu

DEPARTMENT OF AGRICULTURAL AND RESOURCE ECONOMICS

BERKELEY

CALIFORNIA AGRICULTURAL EXPERIMENT STATION

University of California

DEPARTMENT OF AGRICULTURAL AND RESOURCE ECONOMICS
DIVISION OF AGRICULTURE AND NATURAL RESOURCES
UNIVERSITY OF CALIFORNIA AT BERKELEY

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Jianmin Liu

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Gordon C. Rausser

California Agricultural Experiment Station
Giannini Foundation of Agricultural Economics
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Jianmin Liu *

Gordon C. Rausser †

* Ph.D. candidate, Department of Agricultural and Resource Economics, University of California at Berkeley

† Robert Gordon Sproul Distinguished Professor, Department of Agricultural and Resource Economics, University of California at Berkeley

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ABSTRACT

China is the world's largest producer and consumer of cereal grains. As with many other developing countries, providing food security to its 1.13 billion people is of overriding importance to China. In this setting, a model is developed to analyze whether futures trading will enhance China's pursuit of food security. In this model, the government faces resource constraint (fixed amount of land) for agricultural production, and is presumed to achieve an exogenously specified target level of food consumption. The optimal hedging and production decisions are derived simultaneously, subject to the food security objective and the land constraint. The conceptual model shows that participating in futures trading can stabilize the country's optimal land allocation while the empirical analysis shows that, in the case of China, the optimal land allocation for agricultural production is quite different from its current levels.

Keywords: *food security, uncertainty, futures markets, China.*

CAN FUTURES TRADING PLAY A ROLE IN CHINA'S LAND ALLOCATION AND FOOD SECURITY POLICY?

1. Introduction

China is the world's largest producer, and consumer, of cereal grains. As with many other developing countries, providing food security to its 1.13 billion people is of overriding importance to China.[1] Even with China's substantial production capacity, Chinese agricultural policy-makers face the challenge of feeding a large and growing population with a shrinking resource base. China must feed 22 percent of the world's population with 7 percent of the world's arable land (Zhu and Martin, 1989). National food security is and has been of primary importance in the central planners' policy-making process. Over much of the post World War II period, China's strategy in this respect has been largely one of self-reliance (Yang and Tyers, 1989). In essence, the strategy of food self-sufficiency has been pursued, with foreign trade used to supplement shortfalls.

Trade flows are determined through a centralized planning system under the authority of the ministry of foreign trade (MFT). The annual foreign trade planning process identifies the required imports subject to the allocation of foreign exchange. Exports are selected to partially finance the desired level of imports so as to avoid any significant trade deficits that will require foreign borrowing (World Bank, 1988). Nevertheless, despite a tight foreign exchange constraint, China has been importing a substantial amount of grain since 1962 in order to meet its food security targets.

More than 80 percent of China's grain imports is wheat; and in recent decades, China has become the second largest wheat importer (after the Soviet Union). China's cereal import levels reached a historic high of 16.12 million tons in 1982, valued at approximately $2.625 billion (U.S.). Of this total amount of cereal imports, 13.53 million tons was wheat. In 1987, China imported 16.28 million tons of cereal grain, including

13.2 million tons of wheat (State Statistical Bureau, People's Republic of China, 1988).[2] It is expected that China will import more grain as its population and per-capita income increase (Halbrendt and Gempesaw, 1990).

As the Chinese economy becomes more open and food imports play a more active role in domestic food security, the transmission of primary product price volatility into the domestic economy will increase. As a major trader on world grain markets, China will have a substantial exposure to world price risk. This risk occurs both because world markets are volatile and because China's production is highly variable. For example, from 1952 to 1986, world wheat, soybean, rice, and cotton prices varied 46.34 percent, 52.92 percent, 50.02 percent, and 35.59 percent, respectively, about their means. During the same period, the coefficient of variation in China's wheat, soybean, rice, and cotton production were 55.52 percent, 175 percent, 31.91 percent, and 47.73 percent, respectively. In the face of this risk, the Chinese government has become increasingly interested in the potential use of futures markets as a vehicle for managing their exposure to market volatility.[3]

In any serious attempts on the part of China to become an active participant on international futures markets, what guidance does the economic literature provide? In the case of food security, many theoretical and empirical analyses have been conducted over the last decade (See Adelman and Berck, 1991; Hazell, Pomareda, and Valdes, 1986; and Reutlinger and Bigman, 1981, for examples). The argument that a country's exposure to world agricultural price and domestic yield risks can be managed by adjusting the domestic agricultural production structure, subject to the food security objective, has been raised by Sarris (1985). But the risk-reducing role of futures trading is not considered in the Sarris formulation. In another approach, Gordon and Rausser (1984) introduced a model of country hedging for minimizing the random variability of a country's purchasing power. In their model, the domestic production structure was exogenous and no attempt was made to derive an optimal risk management strategy. Rolfo (1980)

Table 1. Notation for Model

Notation	Interpretation
a	subscript representing agricultural goods that have only spot market
af	subscript representing agricultural goods that have both spot and futures markets
X_a	$(m \times 1)$ vector of domestic production in the second period for category a
X_{af}	$(n \times 1)$ vector of domestic production of in the second period for category af
X_n	domestic production for nonagricultural goods in the second-period
C_a	$(m \times 1)$ vector of the second-period domestic consumption for category a;
C_{af}	$(n \times 1)$ vector of the second-period domestic consumption for category af
C_n	the second-period domestic consumption for nonagricultural goods
P_a	$(m \times 1)$ vector of the second-period spot price of category a
P_{af}	$(n \times 1)$ vector of the second-period spot price vector of category af
P_{af}^f	$(n \times 1)$ vector of futures price quoted in the first-period for category af
H_a	$(n \times 1)$ vector of first-period forward sales (or purchase if $H_a < 0$) of category af
r	spot foreign exchange rates in the second period
r^f	forward foreign exchange rates quoted in the first period
W	amount of foreign exchange sold in futures markets
ϕ	risk parameter
m	number of commodities of category a
n	number of commodities of category af
R_{ca}	expenditures on C_a
R_{caf}	expenditures on C_{af}
R_{xa}	dollar returns from X_a in spot market
R_{xaf}	dollar returns from X_{af} in spot market
R_{af}^f	dollar returns from a unit of category af in futures market
R_w^f	dollar returns from a unit of W in futures market

Solving (1) yields the optimal consumption, C_a, C_{af}, and C_n, as functions of the exogenous variables. Substituting these variables into the planners' utility function yields the second-period indirect utility function, namely

$$V_{t+1}\left[P_a,P_{af},P_{af}^f,P_n,H_a,X_a,X_{af},X_n,W,r,r^f\right]$$

$$\equiv U_{t+1}\Big[C_a^0(P_a,P_{af},P_{af}^f,P_n,H_a,X_a,X_{af},X_n,W,r,r^f),$$

$$C_{af}^0(P_a,P_{af},P_{af}^f,P_n,H_a,X_a,X_{af},X_n,W,r,r^f),$$

$$C_n^0(P_a,P_{af}P_{af}^f,P_n,H_a,X_a,X_{af},X_n,W,r,r^f)\Big]. \qquad (2)$$

In the first-period, the precise values of P_a, P_{af}, P_n, X_a, X_{af}, X_n and r are unknown; only their joint probability distribution is known. Hence, the optimization problem in the first-period is of the form,

$$\max_{H_a,W} E\left[V_t(P_a,P_{af},P_{af}^f,P_n,H_a,X_a,X_{af},X_n,W,r,r^f)\right] \qquad (3)$$

$$s.t.\ T(\overline{X}_a,\overline{X}_n) \leq 0,$$

where an overbar denotes expected value, and the inequality is a compact notation for the technical production constraints facing the country (e.g. the fixed amount of arable land). The expectation in (3) is taken over the joint probability distribution of all stochastic variables.

To achieve tractability, it is presumed that nonagricultural production and price are fixed exogenously,[4] and that the price of nonagricultural goods is the numeraire, $P_n = 1$. Throughout the optimization process, the two consumption vectors of agricultural goods, $\overline{C}_a$ and $\overline{C}_{af}$, are exogenously specified in the first period by the central planners, where the overbar represents targets of consumption level. To achieve these goals, the government relies on trade to fulfill the food shortage. The particular value of this vector is obtained from detailed analysis of consumption patterns among various income classes, coupled with government evaluation of the needs of the population, and government consumer price policies. In the formulation advanced here, food consumption bundles $\overline{C}_a$, and $\overline{C}_{af}$, are taken as given.

For the past four decades, especially in urban areas, the Chinese central government has rationed domestic food consumption. A fixed amount of grain is basically allocated for each individual on a monthly basis at heavily subsidized prices by the government (Lardy, 1990, p. 2).[5] In fact, this rationing serves as the target level of domestic consumption; and the government's objective is to achieve this goal. Since domestic prices are not determined by market forces, the rationing system is used by the government to clear the domestic market.

Given the assumption of exogenously specified $\overline{C}_a$ and $\overline{C}_{af}$, the two-period problem outlined earlier is greatly simplified. This is because the second-period non-stochastic budget constraint determines the consumption of nonagricultural products, C_n:

$$C_n^0 = P_a' X_a + P_{af}' X_{af} + (P_{af}^f - P_{af})' H_a + X_n^* - P_a' \overline{C}_a - P_{af}' \overline{C}_{af} + (r^f - r) W \quad (4)$$

where X_n^* represents the exogenous nonagricultural production. Substituting C_n into (2), the indirect utility function in the second-period is:

$$U_{t+1} \left[\overline{C}_a, \overline{C}_{af}, P_a' X_a + P_{af}' X_{af} + (P_{af}^f - P_{af})' H_a + X_n^* - P_a' \overline{C}_a - P_{af}' \overline{C}_{af} + (r^f - r) W \right]$$

$$\equiv V_{t+1} \left[P_a' X_a + P_{af}' X_{af} + (P_{af}^f - P_{af})' H_a + (r^f - r) W - P_a' \overline{C}_a - P_{af}' \overline{C}_{af} + X_n^* \right]. \quad (5)$$

Alternatively, the indirect utility function in (5) can be expressed as

$$V_{t+1} = V_{t+1} \left[P_a, P_{af}, P_{af}^f, H_a, X_a, X_{af}, X_n^*, W, r, r^f \right]. \quad (6)$$

Similarly, the first-period maximization problem may now be restated as:

$$\max E \left[V_t \; [P_a' X_a + P_{af}' X_{af} + (P_{af}^f - P_{af})' \, H_a + (r^f - r) W - P_a' \overline{C}_a - P_{af}' \overline{C}_{af} + X_n^*] \right] \quad (7)$$

$$s.t. \; T(\overline{X}_a, \overline{X}_n).$$

A particular functional form for V_t is needed to make the model empirically operational. In this study, an exponential function is employed. Under the assumption of a normal distribution of random variables, the objective becomes equivalent to maximization of a linear function of the expected value and the variance as follows:

$$\max V_t = \max \left[E(R) - \frac{1}{2}\phi Var(R) \right] \tag{8}$$

$$s.t.\ T(\bar{X}_a, \bar{X}_n) \leq 0.$$

where ϕ is the well-known risk parameter; $E(\cdot)$ and $Var(\cdot)$ are, respectively, the expectation and variance operator; and R is of the form,

$$R = \sum_{i=1}^{m} \left[P_{ai} X_{ai} - P_{ai} \bar{C}_{ai} \right] + \sum_{i=1}^{n} \left[P_{ari} X_{afi} + (P_{afi}^{f} - P_{afi}) H_{ai} - P_{afi} \bar{C}_{afi} \right] + (r^f - r) W. \tag{9}$$

Alternatively, R can be written as:

$$R = \sum_{i=1}^{m} R_{cai} + \sum_{i=1}^{n} R_{cafi} + \sum_{i=1}^{m} R_{xai} + \sum_{i=1}^{n} R_{xafi} + \sum_{i=1}^{n} R_{afi}^{f} H_{ai} + R_w^f W. \tag{10}$$

The market returns on the right-hand side of (10) are defined in (A-1) of Appendix 1. In essence, R can be interpreted as net revenue (if $R > 0$) or deficit (if $R < 0$) from the agricultural sector. It is assumed that, if $X_a < \bar{C}_a$, or $X_{af} < \bar{C}_{af}$, then the country will import the amount $(\bar{C}_a - X_a)$ or $(\bar{C}_{af} - X_{af})$ of agricultural products to achieve food security and participate in futures trading to reduce its exposure to price uncertainty in the world market.

In the above model, optimal hedging and production strategies will be derived simultaneously. We assume that production of each crop is equal to the product of random yield and area planted. Let an $(m \times 1)$ vector, Z_a, be the allocation of acreage for production of agricultural goods for which no futures markets exist and an $(n \times 1)$ vector, Z_{af}, be the allocation of acreage for production of agricultural goods for which there do exist futures markets, and

$$X_{ai} = Z_{ai} y_{ai} \qquad (i = 1, \cdots, m) \tag{11}$$

and

$$X_{afj} = Z_{afj} y_{afj} \qquad (j = 1, \cdots, n) \tag{12}$$

where X_{ai}, Z_{ai}, and y_{ai} are, respectively, production output, area planted, and yield of product i that only has spot markets; and X_{afj}, Z_{afj}, and y_{afj} are production output, area planted and yield of product j that has both spot and futures markets, respectively.

For the above specifications, the objective function in the first period becomes

$$V_t = \max_{Z, H_a, W} \left[K'E(F) - \frac{1}{2}\phi\, [\, K'E(FF')K\,] \right]$$

$$s.t. \quad T(\bar{X}_a, \bar{X}_{af}) \leq 0 \tag{13}$$

where vectors F and K are defined as follows:

$$K' = \left[I_0' \;\; Z_a' \;\; Z_{af}' \;\; H_a' \;\; W \right] \tag{14}$$

where K is an $(N \times 1)$ vector of ones, land allocation decisions, and futures positions; $N = (2m + 3n + 1)$; I_0 is an $[(m + 1) \times 1]$ vector of ones, and Z_a is an $(m \times 1)$ vector of acreage allocated to production of m agricultural goods for which no futures market exists. Z_{af} is an $(n \times 1)$ vector of acreage allocated to production of n agricultural goods for which there do exist futures markets.

$$F' = \left[R_{ca}' \;\; R_{caf}' \;\; R_{xa}' \;\; R_{xaf}' \;\; R_{af}' \;\; R_w^f \right] \tag{15}$$

where F is an $(N \times 1)$ vector of returns in spot and futures markets. Note that, in (15), $R_{xa} = P_a y_a$ is the product of spot price and yield of agricultural good for which no futures market exists, and $R_{xaf} = P_{af} y_{af}$ is the product of spot price and yield of agricultural good for which there exists futures market.

In order to isolate the three decision vectors, Z_a, Z_{af} and H_a, and the decision scalar, W, we may rewrite K and F in the following partitioned forms:

$$K' = \left[I_0' \mid K_1' \right] \tag{16}$$

and

$$F' = \left[F_0' \mid F_1' \right] \tag{17}$$

where K_1', F_0' and F_1' are, respectively, the following vectors

$$K_1' = \left[Z_a' \;\; Z_{af}' \;\; H_a' \;\; W \right] \; of \; dimension \; [1 \times (m + 2n + 1)] \tag{18}$$

$$F_0' = \left[R_{ca}' \;\; R_{caf}' \right] \; of \; dimension \; [1 \times (m + n)] \tag{19}$$

$$F_1' = \left[R_{xa}' \;\; R_{xaf}' \;\; R_{af}^{f'} \;\; R_w^f \right] \; of \; dimension \; [1 \times (m + 2n + 1)]. \tag{20}$$

Note that R_w^f is a scalar.

For the first period, maximization of (13) is subject to the simple constraint representing the total cropped land area, namely,

$$\sum_{i=1}^{m} Z_{ai} + \sum_{j=1}^{n} Z_{afj} = A \tag{21}$$

where A represents the total amount of arable land available. Solving (21) for land allocation to the production of commodity (say, m), then we have Z_{am} expressed as:

$$Z_{am} = A - \sum_{i=1}^{m-1} Z_{ai} - \sum_{j=1}^{n} Z_{afj}. \tag{22}$$

Substituting Z_{am} into (13) and solving the resulting quadratic programming problem give us the optimal solutions to production and hedging decisions. Since Z_{am} can be obtained from the constraint in (22), it is dropped from the vector of decision variables, K_1. Consequently, the number of decision variables representing land allocation reduces from $(m + n)$ to $(m + n - 1)$. We denote the new vector of land decision variables as $\tilde{Z}_1$ and the corresponding vector of decision variables as $\tilde{K}_1$, i.e.,

$$\tilde{K}_1' = \left[\tilde{Z}_a' \, Z_{af}' \, H_a' \, W' \right] \quad of \; dimension \; [1 \times (m + 2n)] \tag{23}$$

where $\tilde{K}_1$ is the vector of decision variables representing land allocations, commodity and financial hedges.

The relevant first-order conditions with respect to $\tilde{K}_1$ are:

$$\tilde{K}_1 = \frac{1}{\phi}\tilde{S} - \Lambda I_0 - \Omega \tilde{K}_1 \tag{24}$$

where matrices $\tilde{S}$, Λ and Ω are defined in Appendix 2. From (24) we can obtain the vector of optimal decision variable $\tilde{K}_1^*$:

$$\tilde{K}_1^* = \Psi^{-1}\left[\frac{1}{\phi}\tilde{S} - \Lambda I_0\right] \tag{25}$$

where $\Psi = \left[I + \Omega\right]$ is the dimension of $[(m + 2n) \times (m + 2n)]$ and I is an $[(m + 2n) \times (m + 2n)]$ identity matrix, Λ is an $[(m + 2n) \times (m + n)]$ matrix, I_0 is an $[(m + n) \times 1]$ vector of ones, and $\tilde{S}$ is an $[(m + 2n) \times 1]$ vector.

Equation (25) can be used to estimate the optimal acreage allocation for agricultural goods with futures markets, $Z_{af}' = \left[Z_{af1}, \cdots, Z_{afn}\right]$ and for those without futures markets, $Z_a' = \left[Z_{a1}, \cdots, Z_{am}\right]$, optimal hedges of agricultural products that have futures $H_a' = [h_1, ..., h_n]$, and the optimal amount of currency to trade forward, W, for selected values of the risk parameter ϕ.

From equation (25) some comparative statics results can be derived that illustrate the effects of food security policy changes on the optimal production and hedging decisions. It can be seen from Appendix 2 that, in equation (25), Ψ and $\tilde{S}$ are not affected by the levels of R_{ca} and R_{caf}, defined as $R_{ca} = -P_a\bar{C}_a'$ and $R_{caf} = -P_{af}\bar{C}_{af}$, respectively. Therefore, Ψ and $\tilde{S}$ are independent of $\bar{C}_a$ and $\bar{C}_{af}$. Note also that Λ is a function of covariance between expenditure on food consumption (i.e., R_{ca} and R_{caf}) and returns from production in both spot and futures markets. Totally differentiating equation (25) with respect to $\bar{C}_a$ and $\bar{C}_{af}$ shows the effect of a small change in the amount of an exogenously specified food-consumption bundle on the optimal-hedging decision, viz:

$$\frac{d\tilde{K}_1^*}{d\bar{C}_a} = -\Psi^{-1} \cdot \frac{d\Lambda}{d\bar{C}_a} \cdot I_0 = 0, \tag{26}$$

$$\frac{d\tilde{K}_1^*}{d\bar{C}_{af}} = -\Psi^{-1}\cdot\frac{d\Lambda}{d\bar{C}_{af}} \cdot I_0 = 0. \tag{27}$$

Equations (26) and (27) lead to the following proposition:

Proposition 1 :

The incremental changes in the target level of food consumption do not lead to changes of the optimal amount of land allocated for the corresponding production, or for that matter, changes in the optimal hedging decisions. Thus, adjustments of resource allocation can be smoothed through futures market hedging.

In the above proposition, the access to futures trading is crucial. This can be shown by demonstrating the opposite; namely, that, in the absence of futures markets, consumption targets affect the optimal land allocations. Essentially, if a country optimally participates in futures trading, the adjustment of land allocation induced by moderate changes in target consumption level can be avoided, as can the transaction costs of resource reallocations.

Totally differentiating equation (25) with respect to risk parameter, ϕ, we have:

$$\frac{dK_1^*}{d\phi} = -\frac{1}{\phi^2}\Psi^{-1}\tilde{S}. \tag{28}$$

The sign of (28) is ambiguous, depending on the matrix Ψ^{-1}. This means, of course, that the possibility for the counter-intuitive results (in the absence of futures markets) remains. Equation (28) leads to the following proposition:

Proposition 2:

An incremental increase of a country's level of risk aversion may not lead to an increase of land allocation to food production.

The underlying intuition of *Proposition 2* is that, with the access of the futures markets, a country may reduce risk by futures trading rather than pursuing the self-reliance policy by increasing land allocation to the food production. This finding is important for a planned-economy because, among other advantages, it suggests that international trade is also an important tool for reducing risk.

3. An Example of Joint Hedging and Production Decision in a Two-Commodity Case

To gain further insight into the general formulation, consider a simplified version with two crops, denoted by scripts 1 and 2, respectively, for which there exist spot and futures markets, as well as a composite nonagricultural product. The exchange rate is considered fixed and therefore is not included in the objective function.[6] Furthermore, assume $Cov(P_i, y_j) = 0$ for $i, j=1,2$. As a result, the mean and variance of R, as well as the indirect utility function, $V(\cdot)$, can be expressed as

$$E(R) = Z'a - d'P + (P^f - \bar{P})'H \tag{29}$$

$$Var(R) = Z' \cdot M \cdot Z + (H + \bar{C})' \cdot C \cdot (H + \bar{C}) - 2Z' \cdot G \cdot (\bar{C} + H) + 2\bar{C} \cdot C \cdot H \tag{30}$$

$$V(Z,H) = Z'e - d'P + \left[P^f - \bar{P}\right]' \cdot H$$

$$- \frac{\phi}{2}\left[(Z' \cdot M \cdot Z) + \bar{C}' \cdot C \cdot \bar{C} + H' \cdot C \cdot H\right] + \phi(Z' \cdot G - \bar{C}' \cdot C) \cdot H \tag{31}$$

where

$Z = (Z_i)$: (2×1) vector of acreage allocation for agricultural production
$P = (P_i)$: (2×1) vector of spot price, $i = 1,2$
$P^f = (P_i^f)$: (2×1) vector of futures prices, $i = 1,2$
$X = (X_i)$: (2×1) vector of output, $X_i = Z_i y_i \quad i = 1,2$
$s_{ij} = Cov(P_i, P_j)$: price covariance for crops i and j
$\sigma_{ij} = Cov(y_i, y_j)$: yield covariance of crops i and j
$a_i = \bar{P}_i \bar{y}_i$: product of expected price and yield for product; $i=1,2$
$a = (a_i)$: (2×1) vector
$C = (s_{ij})$: (2×2) price covariance matrix; $i;j = 1,2$
$\bar{C} = (\bar{C}_i)$: (2×1) vector of food consumption targets; $i,j=1,2$
$G = (g_{ij}) = \bar{y}_i s_{ij}$: (2×2) covariance matrix; $i,j = 1,2$
$H = (H_i)$: (2×1) vector of optimal hedge for $i = 1,2$
$e = a + \phi \cdot G \cdot \bar{C}$
$\mu_{ij} = \sigma_{ij} s_{ij} + \bar{y}_i \bar{y}_j s_{ij} + \bar{P}_i \bar{P}_j \sigma_{ij}$; $i,j=1,2$
$M = (\mu_{ij})$: (2×2) matrix.

Note that, in general, G is not a symmetric matrix, i.e., $g_{ij} \neq g_{ji}$ since $\bar{y}_i \neq \bar{y}_j$. The decision variables in the optimization problem are Z_i and H_i, $(i=1,2)$, reflecting decisions on acreage allocation to agricultural production of x_1 and x_2 and on the hedging decision for these two goods. The optimization process and the set of decision variables are the special case of those expressed in (13) and (14), respectively. As for the general formulation, (31) is maximized subject to the simple restriction that total cropped land area is fixed,

$$Z_1 + Z_2 = A. \tag{32}$$

Assuming an interior solution, we obtain the optimal land allocation and hedging decisions for crops 1 and 2 below.

$$Z_1^* = \frac{e_1 - e_2 + \phi\left[(g_{11} - g_{21})H_1^* + (g_{12} - g_{22})H_2^*\right] + \phi A\,(\mu_{22} - \mu_{12})}{\Delta\phi} \tag{33}$$

$$Z_2^* = \frac{e_2 - e_1 + \phi\left[(g_{12} - g_{12})H_2^* + (g_{11} - g_{21})H_1^*\right] + \phi A\,(\mu_{11} - \mu_{12})}{\Delta\phi} \tag{34}$$

$$H_1^* = \frac{s_{22}(P_1^f - \bar{P}_1) - s_{12}(P_2^f - \bar{P}_2) - \phi\Pi_1 + \phi\Pi_2 Z_1^*}{\phi\Theta} \tag{35}$$

$$H_2^* = \frac{s_{11}(P_2^f - \bar{P}_2) - s_{12}(P_1^f - \bar{P}_1) - \phi\Pi_3 + \phi\Pi_4 Z_1^*}{\phi\Theta} \tag{36}$$

where

$$e_1 = \bar{P}_1\bar{y}_1 + \phi(g_{11}\bar{C}_1 + g_{12}\bar{C}_2)$$

$$e_2 = \bar{P}_2\bar{y}_2 + \phi(g_{21}\bar{C}_1 + g_{22}\bar{C}_2)$$

$$\Delta = \mu_{11} - 2\mu_{12} + \mu_{22}$$

$$\Theta = s_{11}s_{22} - s_{12}^2$$

$$\Pi_1 = \Theta\bar{C}_1 + (s_{12}g_{22} - s_{22}g_{21})A$$

$$\Pi_2 = \Theta\bar{y}_1$$

$$\Pi_3 = \Theta\bar{C}_2 + (s_{11}g_{22} - s_{12}g_{21})A$$

$$\Pi_4 = \Theta\bar{y}_2.$$

From equations (33) and (34), it can be seen that introducing futures trading will affect production decisions and, thus, the country's well being. As it can be seen in (33) and (34), the production and hedging decisions are interdependent.

All terms in (33) through (36) are observable except the risk parameter, ϕ, which reflects the country's subjective attitude toward risk. If the country's decisions to hedge are made after the production decision, then (35) and (36) give the optimal hedging decisions as functions of the acreage allocation decisions. Solving equations (33) to (36) simultaneously for Z_1^*, Z_2^*, H_1^*, and H_2^* gives us the reduced form of the optimal value of production and hedging. Letting $\Gamma = \Theta[\Delta - \bar{y}_1^2 s_{11} + 2\bar{y}_1\bar{y}_2 s_{12} - \bar{y}_2^2 s_{22}]$,

$$Z_1^* = \frac{\left[(e_1 - e_2) + \phi A\,(\mu_{22} - \mu_{12})\right]\Theta}{\phi\Gamma}$$

$$+ \frac{\left[(g_{11} - g_{21})s_{22} + (g_{22} - g_{12})s_{12}\right](P_1^f - \bar{P}_1)}{\phi\Gamma}$$

$$+ \frac{\left[(g_{12} - g_{22})s_{11} + (g_{21} - g_{11})s_{12}\right](P_2^f - \bar{P}_2)}{\phi\Gamma}$$

$$+ \frac{(g_{21} - g_{11})\Pi_1 + (g_{22} - g_{12})\Pi_3}{\Gamma}. \tag{37}$$

Using the constraint, $Z_2^* = A - Z_1^*$, we can obtain the optimal amount of land allocated for the production of the other crop. The optimal hedging decisions are

$$H_1^* = \frac{s_{22}(P_1^f - \bar{P}_1) - s_{12}(P_2^f - \bar{P}_2) - \phi\Pi_1}{\phi\Theta}$$

$$+ \frac{\left[(e_1 - e_2) - \phi A\,(\mu_{22} - \mu_{12})\right]\Pi_2}{\phi\Gamma}$$

$$+ \frac{\left[[(g_{11} - g_{21})s_{22} + (g_{22} - g_{12})s_{12}](P_1^f - \bar{P}_1)\right]\Pi_2}{\phi\Theta\Gamma}$$

$$+\frac{\Big[[(g_{12}-g_{22})s_{11}+(g_{21}-g_{11})s_{12}](P_2^f-\bar{P}_2)\Big]\Pi_2}{\phi\Theta\Gamma}$$

$$+\frac{\Big[(g_{21}-g_{11})\Pi_1+(g_{22}-g_{12})\Pi_3\Big]\Pi_2}{\Theta\Gamma}, \tag{38}$$

and

$$H_2^* = \frac{s_{11}(P_2^f-\bar{P}_2)-s_{12}(P_1^f-\bar{P}_1)-\phi\Pi_3}{\phi\Theta}$$

$$+\frac{\Big[(e_1-e_2)-\phi A\,(\mu_{22}-\mu_{12})\Big]\Pi_4}{\phi\Gamma}$$

$$+\frac{\Big[[(g_{11}-g_{21})s_{22}+(g_{22}-g_{12})s_{12}](P_1^f-\bar{P}_1)\Big]\Pi_4}{\phi\Theta\Gamma}$$

$$+\frac{\Big[[(g_{12}-g_{22})s_{11}+(g_{21}-g_{11})s_{12}](P_2^f-\bar{P}_2)\Big]\Pi_4}{\phi\Theta\Gamma}$$

$$+\frac{\Big[(g_{21}-g_{11})\Pi_1+(g_{22}-g_{12})\Pi_3\Big]\Pi_4}{\Theta\Gamma}. \tag{39}$$

If the futures price is the unbiased estimate of spot price (i.e., $P^f=\bar{P}$), then the optimal production and hedging decisions can be expressed as

$$Z_1^* = \frac{\Big[(e_1-e_2)-\phi A\,(\mu_{22}-\mu_{12})\Big]\Theta}{\phi\Gamma}+\frac{(g_{21}-g_{11})\Pi_1+(g_{22}-g_{12})\Pi_3}{\Gamma}, \tag{40}$$

$$Z_2^* = A - Z_1^*, \tag{41}$$

$$H_1^* = -\frac{\Pi_1}{\Theta}+\frac{\Big[(e_1-e_2)-\phi A\,(\mu_{22}-\mu_{12})\Big]\Pi_2}{\phi\Gamma}$$

$$+\frac{\Big[(g_{21}-g_{11})\Pi_1+(g_{22}-g_{12})\Pi_3\Big]\Pi_2}{\Theta\Gamma}, \tag{42}$$

and

$$H_2^* = -\frac{\Pi_3}{\Theta} + \frac{\left[(e_1 - e_2) - \phi A(\mu_{22} - \mu_{12})\right]\Pi_4}{\phi\Gamma}$$

$$+ \frac{\left[(g_{21} - g_{11})\Pi_1 + (g_{22} - g_{12})\Pi_3\right]\Pi_4}{\Theta\Gamma}. \tag{43}$$

In the above optimization problem, if we ignore the futures market, implying that $H_1^* = H_2^* = 0$ in equations (33) and (34), then the only control variables are the land allocation decisions. Thus, the optimal production strategies can be obtained by maximizing (31) for Z_1^* and Z_2^*, and

$$Z_1^* = \frac{e_1 - e_2 + \phi A(\mu_{22} - \mu_{12})}{\Delta\phi}, \tag{44}$$

$$Z_2^* = \frac{e_2 - e_1 + \phi A(\mu_{11} - \mu_{12})}{\Delta\phi}. \tag{45}$$

In fact, equation (44) is a special case of (33) by assuming away futures trading. From the viewpoint of the two-period problem, in the absence of futures markets, exogenously specified target levels of agricultural consumption can be thought of as additional constraints on the second-period problem; and as such, it will lower the value of the indirect utility function. However, in the presence of futures trading, the country can choose the optimal hedging strategy to reduce the risk for the given level of expected return from its trade, while still fulfilling the food security objective. Simply, combining access to futures markets with trade policy allows a country seeking a food security objective to improve its resource allocation and reduce the magnitude of its exposure to the risk in the world market.

From (37) we obtain the following comparative statics results.

$$\frac{\partial Z_1^*}{\partial \bar{C}_1} = \frac{\Theta}{\Gamma}\left[g_{11} - g_{21} + g_{21} - g_{11}\right] = 0 \tag{46}$$

$$\frac{\partial Z_1^*}{\partial \bar{C}_2} = \frac{\Theta}{\Gamma}\left[g_{12} - g_{22} + g_{22} - g_{12}\right] = 0. \tag{47}$$

Equations (46) and (47) imply that an incremental increase in the average domestic demand of good i (i = 1,2) will not change the optimum amount of land allocated to its production. This finding is a special case of *Proposition 1.* The comparative statics in (46) and (47) form a clear contrast to those in Sarris (1985), which showed that in the absence of futures trading changes in consumption would affect land allocations.[7] This contrast suggests that a country's participation in futures trading can substantially reduce the influence of the change of average domestic demand of good i on the optimal amount of land allocated to production of good i and, therefore, reduce the variability of domestic production caused by fluctuation of acreage. This leads to the following proposition:

Proposition 3

> *If prohibited from futures trading, incremental changes in national food consumption targets will affect land allocation decisions to agricultural production. If the price of the two crops are negatively correlated, then the increase of target level of food consumption will lead to an increase in the amount of land allocated for the corresponding production. However if the prices of the two crops are positively correlated and the correlation coefficient is large then the increase will lead to the decrease of the amount of land allocated to the corresponding production.*

When we compare *Proposition 3* with *Proposition 1* it becomes obvious that adding access to futures markets to a country's trade policy can stabilize the country's land allocation decisions. Considering substantial transaction costs of resource reallocation in a planned economy, *Proposition 1* and *Proposition 3* provide an important policy implication.

The effects from the marginal change of land constraint, A, and risk aversion parameter, ϕ, on optimal land allocation to production can be obtained from the following comparative statics.

$$\frac{\partial Z_1^*}{\partial A} = \frac{\Theta(\mu_{12} - \mu_{22})}{\Gamma} + \frac{(g_{21} - g_{11})(s_{12}g_{22} - s_{22}g_{21}) + (g_{22} - g_{12})(s_{11}g_{22} - s_{12}g_{21})}{\Gamma} \tag{48}$$

$$\frac{\partial Z_1^*}{\partial \phi} = \frac{\Theta}{\Gamma} \frac{(\bar{y}_1 s_{11} - \bar{y}_2 s_{12})\bar{C}_1 + (\bar{y}_1 s_{12} - \bar{y}_2 s_{22})\bar{C}_2}{\phi}. \tag{49}$$

The expression in (48) does not have a definite sign. Thus, it is possible that both crops should expand in area, or that one should expand and the other one should contract; the result depends on the signs of price and yield correlations, as well as the magnitudes of means and standard deviations of yields and prices. In equation (49), increased aversion to agricultural balance of trade fluctuations does not necessarily lead to increased production of food crops. The sign of the derivative in (49) depends on the relative magnitudes of average yields and the variances and covariance of world prices of goods i=1,2.

In general, we can see that futures trading can effectively reduce the fluctuations in the optimal amount of land allocated to different crops resulting from the changes of average domestic demand for goods. Considering the frequent changes in domestic food policy (for example, changes in the rationing system), futures trading might be an attractive option to reduce the fluctuations in resource allocation and domestic production and accordingly reduce the associated transaction costs.

4. Data, Empirical Analysis, and Results

In this section, simulations on optimal hedging and land allocations for China are conducted. As described earlier, China is a major net wheat importer as well as a major soybean exporter. There exist both spot and active futures markets for wheat and soybeans. The acreages allocated to wheat and soybeans production are essentially controlled by the Chinese government. Thus, the country faces a decision problem for consumption, production, and foreign trade.

The data used in this analysis are the Chinese data on yield, acreage, and foreign trade for wheat and soybeans, as well as spot and futures prices on world markets. Annual data on yield and acreage for wheat and soybeans can be obtained from the *Year Book of China*, and *Nongyie Jingji Ziliao (Agricultural Economics Data)*. Spot and futures prices for wheat and soybean are obtained from the *Commodity Year Book.*

It is assumed that, in the first period, decision-makers choose the amount of wheat and soybeans to hedge in futures markets and allocate the amount of land to wheat and soybean production simultaneously. The production constraint facing the country is that the total land available for wheat and soybean production is fixed--a realistic assumption in the case of China. For the past three decades, the total amount of land allocated to wheat and soybean production has been virtually constant. The coefficient of variation for the total amount of land for wheat and soybean is only 0.05. As a result, we used the average amount of land, 35.603 million hectares, allocated for wheat and soybean production during the period of 1952-1986, as the constraint on land resource.

The simulations on the optimal hedging and acreage allocation of Chinese wheat and soybean production are conducted using equations (37), (38), and (39) under the assumption that China adopts the following hedging strategy: the optimal positions derived from the model are implemented in April (production season) for wheat and soybeans. Import requirements and potential exports are hedged in April by implementing the optimal positions in December for wheat and in November for soybeans, and lifting these positions in the so-called delivery months for each commodity.

Table 2 displays the optimal hedge for wheat and soybeans in 1986, corresponding to selected values of the constant risk aversion parameter, ϕ. The first column is the selected values of the aversion parameter, ϕ, with ∞ representing very high risk aversion, and 1×10^{-12} representing very low risk aversion. The second and third columns contain the optimal hedges for wheat and soybeans, respectively. The fourth and fifth columns contain the hedging ratios, as a proportion of the expected production, for wheat and soybeans, respectively. The last two columns report the optimal land allocation for wheat and soybean production, corresponding to the selected levels of ϕ.

The optimal hedge for wheat and soybeans is negative for all selected values of ϕ, implying the forward purchase. For $\phi > 1\times10^{-8}$, optimal hedges do not vary significantly.

Table 2. Simulations on Optimal Hedge and Land Allocation for Wheat and Soybeans Production, 1986

Risk Aversion Parameter, ϕ	Optimal Hedge: Wheat	Optimal Hedge: Soybeans	Optimal Hedging Ratio[b]: Wheat	Optimal Hedging Ratio[b]: Soybeans	Optimal Acreage Allocation: Wheat	Optimal Acreage Allocation: Soybeans
	--------(thousand metric tons)--------				--------(million hectares)--------	
∞	-3757.200[a]	-663.510	0.096	1.983	14.560	21.043
1×10^{4}	-3757.200	-663.510	0.096	1.983	14.560	21.043
1×10^{2}	-3757.200	-663.510	0.096	1.983	14.560	21.043
1×10^{1}	-3757.200	-663.510	0.096	1.983	14.560	21.043
1.0	-3757.200	-663.510	0.096	1.983	14.560	21.043
1×10^{-1}	-3757.201	-663.510	0.096	1.983	14.560	21.043
1×10^{-2}	-3757.201	-663.510	0.096	1.983	14.560	21.043
1×10^{-3}	-3757.201	-663.510	0.096	1.983	14.560	21.043
1×10^{-4}	-3757.219	-663.509	0.096	1.983	14.560	21.043
1×10^{-5}	-3757.264	-663.508	0.096	1.983	14.560	21.043
3×10^{-6}	-3757.354	-663.507	0.096	1.983	14.561	21.042
8×10^{-7}	-3757.440	-663.505	0.096	1.983	14.562	21.041
4×10^{-7}	-3757.679	-663.500	0.096	1.983	14.563	21.039
2×10^{-7}	-3758.158	-663.490	0.096	1.982	14.567	21.036
1×10^{-7}	-3759.117	-663.469	0.096	1.982	14.574	21.029
5×10^{-8}	-3761.033	-663.429	0.097	1.982	14.587	21.016
1×10^{-8}	-3766.784	-661.500	0.097	1.976	14.628	20.975
1×10^{-9}	-3853.037	-659.490	0.099	1.971	15.238	20.365
1×10^{-10}	-3948.874	-623.312	0.101	1.862	15.916	19.687
1×10^{-11}	-4352.135	-261.530	0.112	1.781	24.120	11.483
8×10^{-12}	-4673.944	-161.035	0.146	0.481	28.560	7.043
7×10^{-12}	-5273.341	-89.253	0.146	0.267	28.781	6.822
6×10^{-12}	-5673.012	6.456	0.146	0.019	29.060	6.543

[a] Negative signs represent forward purchase.
[b] Optimal hedge as a proportion of the expected production.
Source: Computed.

Table 3. Simulations on Optimal Land Allocation for Wheat and Soybean Production without Futures Trading

Risk Aversion Parameter, ϕ	Optimal Acreage Allocation Wheat	Soybeans
	-------(million hectares)-------	
∞	25.220	10.383
1×10^{4}	25.220	10.383
1×10^{2}	25.220	10.383
1×10^{1}	25.220	10.383
1×10^{0}	25.220	10.383
1×10^{-1}	25.220	10.383
1×10^{-2}	25.220	10.383
1×10^{-3}	25.220	10.383
1×10^{-4}	25.220	10.383
1×10^{-5}	25.220	10.383
3×10^{-6}	25.220	10.383
8×10^{-7}	25.220	10.383
4×10^{-7}	25.220	10.383
2×10^{-7}	25.220	10.383
1×10^{-7}	25.220	10.383
5×10^{-8}	25.215	10.388
2×10^{-8}	25.209	10.394
1×10^{-9}	25.109	10.494
1×10^{-10}	24.999	10.604
1×10^{-11}	23.005	12.598
8×10^{-12}	15.554	20.049
7×10^{-12}	10.345	25.258
6×10^{-12}	9.238	26.365

Source: Computed.

However, the optimal hedge for wheat and soybeans changes significantly for ϕ below 1×10^{-8} and 1×10^{-10}, respectively. When ϕ equals 6×10^{-12}, reverse hedging becomes optimal for soybean production. As ϕ increases, the quantity of optimal hedge for wheat increases, while it decreases in the case of soybeans.

Optimal land allocation for wheat and soybean production does not vary significantly for $\phi > 1 \times 10^{-10}$, but it changes significantly for $\phi < 1 \times 10^{-10}$. In equation (49), the sign of the effect of the marginal change of risk aversion level on optimal land allocation is ambiguous. However, it can be seen from the simulations that, as ϕ decreases, the acreage allocated for wheat production increases, while the acreage allocated for soybean production decreases. When $\phi \rightarrow \infty$, the optimal acreage allocated for wheat and soybean production is 14.560 and 21.043 million hectares, respectively.

Table 3 shows the simulations on the optimal land allocation for wheat and soybean production if futures trading is prohibited. The selected values of ϕ are listed in the first column. The optimal land allocation for wheat and soybean production, corresponding to the selected values of ϕ are displayed in columns there and four, respectively. It can be seen from Table 3 that, the optimal acreage allocation for wheat and soybean production do not vary significantly for $\phi > 1 \times 10^{-10}$. However, it changes significantly for $\phi < 1 \times 10^{-10}$. It can also be seen that, as ϕ increases, the optimal acreage allocated for wheat production decreases while the allocation for soybean production increases. When $\phi \rightarrow \infty$, the optimal land allocated to wheat and soybean production is 25.220 million and 10.383 million hectares, respectively.

The above findings suggest that the integration of international futures trading with China's trade policy will significantly affect the optimal land allocation for agricultural production and that the country's attitude toward risk will also affect the optimal hedging and land allocation decisions.

5. Conclusion

In this paper we show how the optimal resource allocation and hedging strategy can be determined for a producing country, subject to national food security, resource constraints, and variability in both the price and production. Actual quantitative results are presented for Chinese wheat and soybean production as well as trade in this case study.

The results show that, when participating in futures trading, incremental changes of the amount of exogenously specified target level of food consumption do not change the amount of land allocated to the corresponding production and hedging decision. Thus, adding access to futures markets to a country's trade policy can stabilize the country's optimal land allocation planning.

Empirical simulations for China reveal that, with access to futures trading, the land allocation for wheat production will increase as the risk aversion increases and the land allocation for soybean production will decrease. However, when futures trading is ignored, land allocation for wheat production will decrease as risk aversion increases, and the land allocation for soybean production will increase. Specifically, the optimal acreage allocated for wheat production is about 73.2% more than the optimal acreage allocated to wheat production when futures trading is allowed. These findings provide a clear contrast to the optimal joint solution, which integrates futures markets and land allocation planning. This contrast indicates that ignoring futures trading in a centrally-planned economy may result in serious bias in resource (land) allocations. Moreover, this potential bias in resource allocation suggests that integrating futures trading and production planning can play an important role in national food security policy.

FOOTNOTES

1. In a 1990 state-run *Beijing Review* article, it was stated that without a sound agricultural sector and food security as an economic cornerstone . . . "there would be no stable development for the entire nation" (*Beijing Review,* Vol. 33, July 9, 1990, p. 10).

2. China is also an important importer of other agricultural goods. For example, a cotton sale of 500,000 bales to China, billed as the largest single cotton deal ever (valued at about $200 million) was announced on October 31, 1990 by the Dunavant Enterprises Inc. of Memphis, U.S.A. (Associated Press, October 31, 1990).

3. According to the *Beijing Review* (Vol. 33, July 9, 1990, p. 10), China was making preparations to open its first wholesale grain market in Zhengshou, capital of the Hennan province, in September, 1990. On this market,

> "forward contracts will be allowed and efforts will be made to bring futures--bulk commodities bought for future acceptance or sold for future delivery--gradually into the market. When conditions permit, China will not only turn Zhengshou facility into a futures market for wheat, but also introduce the practice to the trade of other crops including corn, rice, and soybeans."

Even though this wholesale grain market is primarily for domestic trade, it is viewed as a first step toward the international futures markets. In addition, the Chicago Board of Trade has been training and advising Chinese personnel on the mechanics of futures trading.

4. A similar assumption can be found in Sarris (1985) concerning Egypt. This is a realistic assumption for the Chinese economy. For a more detailed discussion, see The World Bank (1988).

5. In China, the rationing of grain retail is called "dingliang" which, on average, is about 16 Kg per month for each adult male and slightly less for adult females (personal conversations with Professor Xiji An, vice president of the Chinese Agricultural Economics Association, 1988 and personal experience).

6. The underlying scenario of this assumption is that the central planners are concerned

about the revenue from tradable goods measured in foreign currency. This is because, in some developing countries the central government monopolizes foreign exchange. However, the central planners have direct control over the domestic price. This is particularly true in China (The World Bank, 1988). Since the domestic price is distorted and does not, in the short run, reflect market forces, the policy makers are essentially concerned about trade revenue in foreign currency.

7. It is interesting to compare equations (46) and (47) with Sarris' comparative statics results. From (44) we have

$$\frac{\partial Z_1^*}{\partial \bar{C}_1} = \frac{\bar{y}_1 s_{11} - \bar{y}_2 s_{12}}{\Delta} \tag{A}$$

and

$$\frac{\partial Z_1^*}{\partial \bar{C}_2} = \frac{\bar{y}_1 s_{12} - \bar{y}_2 s_{22}}{\Delta}. \tag{B}$$

As Sarris showed, if we write $s_{ij} = r_{ij} s_i s_j$ where r_{ij} is the correlation coefficient between P_i and P_j and s_i $(i = 1,2)$ are the standard deviations of P_i then from (A) and (B) we find that if, $r_{12} < 0$, then $(\partial Z_1^*)/(\partial \bar{C}_1) > 0$ and $(\partial Z_1^*)/(\partial \bar{C}_2) < 0$. In other words, increases in the average domestic demand of good i will increase the optimum amount of land allocated to its production. If, however, $r_{12} > 0$, then it is possible that $(\partial Z_1^*)/(\partial \bar{C}_1) < 0$. In fact, according to (A) this will happen if $1 \geq r_{12} > \bar{y}_1 s_1 / \bar{y}_2 s_2$. Hence, if there is a large positive correlation between international prices of food and cash crops, it is optimal to increase the area allocated to cash crops and diminish the area cultivated by food crops. In both of these cases, the optimal amount of land allocated to crop i is affected by the change of the average domestic demand of good i. The direction of the influence of the change of domestic demand on the optimal allocation of land depends on the correlation of world prices between goods i and j.

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Appendix 1: Matrix of Market Returns

To show how equation (8) can be constructed, first rewrite equation (10) as

$$R = \sum_{i=1}^{m} R_{cai} + \sum_{i=1}^{n} R_{cafi} + \sum_{i=1}^{m} R_{xai} + \sum_{i=1}^{n} R_{xafi} + \sum_{i=1}^{n} H_{ai} R_{afi}^{f} + WR_{w}^{f}, \qquad \text{(A-1)}$$

where

$R_{cai} = - P_{ai} \overline{C}_{ai}$ is expenditure (negative revenue) on consumption of the ith agriculture goods that have only spot markets,

$R_{cafi} = -P_{afi} \overline{C}_{afi}$ is expenditure on consumption of the ith agriculture goods that has both spot and futures markets,

spot market of the agriculture product that has only spot markets,

$R_{xafi} = P_{afi} X_{afi}$, is returns in the spot market of the agricultural products that have both spot and futures markets,

$H_{ai} R_{afi}^{f}$ is the return in the futures markets for the ith commodity, where $R_{afi}^{f} = (P_{afi}^{f} - P_{afi})$,

$W \cdot R_{w}^{f}$ is the return in the currency futures market, where $R_{w}^{f} = (r^{f} - r)$.

Then, for convenience in deriving the optimal solution for commodity and currency hedging, the net revenue generated by agricultural sector, R can be rewritten in matrix:

$$R = K'F, \qquad \text{(A-2)}$$

where K: an $(N \times 1)$ vector of an exogenously specified consumption bundles and futures positions where $N = (2m + 3n + 1)$, m is the number of agricultural products for which no futures markets exist, n is the number of agricultural products for which there exists a futures markets do exist.

$$K' = \left[I_0' \;\; H_a' \;\; W \right], \qquad \text{(A-3)}$$

F: an $(N \times 1)$ vector of cash and futures return, and

$$F' = \left[R_{ca}' \;\; R_{caf}' \;\; R_{xa}' \;\; R_{xaf}' \;\; R_{af}^{f'} \;\; R_{w}^{f} \right], \;\; where \qquad \text{(A-4)}$$

I_0: a $[2(m + n) \times 1]$ vector of ones; R_{ca}: an $(m \times 1)$ vector of expenditures on consumption of m agriculture goods that have only spot markets;

$$R_{ca}' = \left[R_{ca1}, \ldots, R_{cam} \right], \qquad \text{(A-5)}$$

R_{caf}: an $(n \times 1)$ vector of expenditures on consumption of n commodities that have both spot and futures markets, and

$$R'_{caf} = \left[R_{caf1}, \ldots, R_{cafn}\right], \tag{A-6}$$

R_{xa}: an $(m \times 1)$ vector of revenues from production of m commodities that have only spot markets, and

$$R'_{xa} = \left[R_{xa1}, \ldots, R_{xam}\right], \tag{A-7}$$

R_{xaf}: an $(n \times 1)$ vector of revenue from production of n commodities that have both spot and futures markets, and

$$R'_{xaf} = \left[R_{xaf1}, \cdots, R_{xafn}\right], \tag{A-8}$$

and W is the scalar representing the amount of currency hedge.

In order to isolate the $(n \times 1)$ decision vector H_a and the scalar W, K and F may be written in the following partitioned forms:

$$K' = \left[I'_0 \mid K'_1\right] \tag{A-9}$$

$$F' = \left[F'_0 \mid F'_1\right], \tag{A-10}$$

where K'_1, F'_0 and F'_1 are defined as;

$$K'_1 = \left[H'_a \;\; W\right] \text{ of dimension } [1 \times (n+1)], \tag{A-11}$$

$$F'_0 = \left[R'_{ca} \;\; R'_{caf} \;\; R'_{xa} \;\; R'_{xaf}\right] \text{ of dimension } [1 \times 2(m+n)], \tag{A-12}$$

$$F'_1 = \left[R^f_{afi}, \ldots, R^f_{afn} \;\; R^f_w\right] \text{ of dimension of } [1 \times (n+1)]. \tag{A-13}$$

Appendix 2: Construction of Variance-Covariance Matrices

The matrices $\tilde{S}$, Λ and Ω appearing in equation (24) are specifically constructed in Appendix 2 as follows. $\tilde{S}$ is an $[(m+2n) \times 1]$ column vector and

$$\tilde{S}' = \left[S'_{za} \; S'_{zaf} \; S'_{ha} \; S'_w\right], \tag{A-14}$$

where

$$S'_{za} = \left[S_{za_1}, \cdots, S_{za_{m-1}}\right], \tag{A-15}$$

$$S_{zai} = \frac{E(R_{xa,i}) - E(R_{xa,m})}{[\Delta_{S_{zai}}]}, \tag{A-16}$$

where

$$[\Delta_{S_{zai}}] = \left[Var(R_{xa,i}) + Var(R_{xa,m}) - 2Cov(R_{xa,i}, R_{xa,m})\right], \quad i=1,\ldots,m-1, \tag{A-17}$$

$$S'_{zaf_i} = \left[S_{zaf_1}, \cdots, S_{zaf_n}\right], \tag{A-18}$$

$$S_{zaf_i} = \frac{E(R_{xafj}) - E(R_{xa,m})}{[\Delta_{S_{zafi}}]}, \tag{A-19}$$

where

$$[\Delta_{S_{zafi}}] = \left[Var(R_{xaf,i}) + Var(R_{xa,m}) - 2Cov(R_{xafj}, R_{xa,m})\right], \quad j=1,\ldots,n, \tag{A-20}$$

$$S'_{ha} = \left[S_{ha_1}, \cdots, S_{ha_n}\right], \tag{A-21}$$

$$S_{ha_i} = \frac{E(R^f_{ai})}{Var(R^f_{a_i})}, \tag{A-22}$$

where

$$S'_w = \frac{E(R^f_w)}{Var(R^f_w)}, \tag{A-23}$$

where S_w is a scalar. Λ is an $[(m+2n) \times (m+n)]$ matrix:

$$\Lambda = \begin{bmatrix} \lambda_{11} & \lambda_{12} \\ \lambda_{21} & \lambda_{22} \\ \lambda_{31} & \lambda_{32} \\ \lambda_{41} & \lambda_{42} \end{bmatrix}, \tag{A-24}$$

where

λ_{11} is an $[(m-1)\times m]$ matrix,
λ_{12} is an $[(m-1)\times n]$ matrix,
λ_{21} is an $(n\times m)$ matrix,
λ_{22} is an $(n\times n)$ matrix,
λ_{31} is an $(n\times m)$ matrix,
λ_{32} is an $(n\times n)$ matrix,
λ_{41} is a $(1\times m)$ row vector,
λ_{42} is a $(1\times n)$ row vector,

The elements of the above matrices are presented as follows: let $[i,j]_{\lambda_{11}}$ represent the element in the ith row, jth column of the matrix, for example λ_{11}, and let

$$[\lambda_{1,i}] = \left[Var(R_{xa,i}) + Var(R_{xa,m}) - 2Cov(R_{xa,i},R_{xa,m})\right], \qquad \text{(A-25)}$$

$$[\lambda_{2,i}] = \left[Var(R_{xaf,i}) + Var(R_{xa,m}) - 2Cov(R_{xaf,i},R_{xa,m})\right], \qquad \text{(A-26)}$$

then

$$[i,j]_{\lambda_{11}} = \frac{\left[Cov(R_{ca,j},R_{xa,m}) - Cov(R_{ca,j},R_{xa,i})\right]}{[\lambda_{1i}]}, \quad i=1,...,m-1 \quad j=1,...,m \qquad \text{(A-27)}$$

$$[i,j]_{\lambda_{12}} = \frac{\left[Cov(R_{caf,j},R_{xa,m}) - Cov(R_{caf,j},R_{xa,i})\right]}{[\lambda_{1i}]} \qquad \text{(A-28)}$$

$$+ \frac{A\left[Var(R_{xa,m}) - Cov(R_{xa,i},R_{xa,m})\right]}{[\lambda_{1i}]}, \quad i=1,...,m-1 \quad j=1,...,n$$

$$[i,j]_{\lambda_{21}} = \frac{\left[Cov(R_{ca,j},R_{xa,m}) - Cov(R_{ca,j},R_{xaf,i})\right]}{[\lambda_{2,i}]}, \quad i=1,...,n \quad j=1,...,m \qquad \text{(A-29)}$$

$$[i,j]_{\lambda_{22}} = \frac{\left[Cov(R_{caf,j},R_{xa,m}) - Cov(R_{caf,j},R_{xaf,i})\right]}{[\lambda_{2,i}]}$$

$$+ \frac{\left[Var(R_{xa,m}) - Cov(R_{xaf,i},R_{xa,m})\right]}{[\lambda_{2,i}]}, \quad i=1,...,n \quad j=n \qquad \text{(A-30)}$$

$$[i,j]_{\lambda_{31}} = -\frac{Cov(R_{ca,j}, R^f_{ai})}{Var(R^f_{ai})}, \quad i = 1,\ldots,n \quad j = 1,\ldots,m \tag{A-31}$$

$$[i,j]_{\lambda_{32}} = -\left[\frac{Cov(R_{caf,j}, R^f_{ai})}{Var(R^f_{ai})} + \frac{A\ Cov(R_{ai}, R_{am})}{Var(R^f_{ai})}\right], \quad i=1,\ldots,n \quad j=n \tag{A-32}$$

$$[j]_{\lambda_{41}} = -\frac{Cov(R_{ca,j}, R^f_w)}{Var(R^f_w)}, \quad j = 1,\ldots,m \tag{A-33}$$

$$[j]_{\lambda_{42}} = -\left[\frac{Cov(R_{caf,j}, R^f_w)}{Var(R^f_w)} + \frac{Cov(R^f_w, R_{xa,m})}{Var(R^f_w)}\right], \quad j=1,\ldots,n \tag{A-34}$$

In equation (19) Ω is the following $[(m + 2n) \times (m + 2n)]$ matrix,

$$\Omega = \begin{bmatrix} \omega_{11} & \omega_{12} & \omega_{13} & \omega_{14} \\ \omega_{21} & \omega_{22} & \omega_{23} & \omega_{24} \\ \omega_{31} & \omega_{32} & \omega_{33} & \omega_{34} \\ \omega_{41} & \omega_{42} & \omega_{43} & \omega_{44} \end{bmatrix}; \tag{A-35}$$

where

ω_{11} is an $[(m-1) \times (m-1)]$ matrix,
ω_{12} is an $[(m-1) \times n]$ matrix,
ω_{13} is an $[(m-1) \times n]$ matrix,
ω_{14} is an $[(m-1) \times 1]$ column vector,
ω_{21} is an $[n \times (m-1)]$ matrix,
ω_{22} is an $(n \times n)$ matrix,
ω_{23} is an $(n \times n)$ matrix,
ω_{24} is an $(n \times 1)$ vector,
ω_{31} is an $[n \times (m-1)]$ matrix,
ω_{32} is an $(n \times n)$ matrix,
ω_{33} is an $(n \times n)$ matrix,
ω_{34} is an $(n \times 1)$ vector,
ω_{41} is a $[1 \times (m-1)]$ row vector,
ω_{42} is a $(1 \times n)$ row vector,
ω_{43} is a $(1 \times n)$ row vector,
ω_{44} is a scalar with the value of zero.

Let $[i,j]_{\omega_{ij}}$ represent element in the ith row and jth column of the matrix ω_{ij}, then

$$[i,j]_{\omega_{11}}=\frac{1}{[\lambda_{1,i}]}\Big[Cov(R_{xa,i},R_{xa,m})+Cov(R_{xaj},R_{xa,m})$$

$$-Cov(R_{xa,i},R_{xaj})-Var(R_{xa,m})\Big],\quad i=1,\dots,m-1\quad j=1,\dots,m-1 \qquad \text{(A-36)}$$

$$[i,j]_{\omega_{12}}=\frac{1}{[\lambda_{1,i}]}\Big[Cov(R_{xa,i},R_{xa,m})+Cov(R_{xafj},R_{xa,m})$$

$$-Cov(R_{xa,i},R_{xafj})-Var(R_{xa,m})\Big],\quad i=1,\dots,m-1\quad j=1,\dots,n \qquad \text{(A-37)}$$

$$[i,j]_{\omega_{13}}=\frac{\Big[Cov(R_{aj}^{f},R_{xa,m})-Cov(R_{xa,i},R_{aj}^{f})\Big]}{[\lambda_{1,i}]},\quad i=1,\dots,m-1\quad j=1,\dots,n \qquad \text{(A-38)}$$

$$[i,j]_{\omega_{14}}=\frac{\Big[Cov(R_{w}^{f},R_{xa,m})-Cov(R_{xa,i},R_{w}^{f})\Big]}{[\lambda_{1,i}]},\quad i=1,\dots,m-1 \qquad \text{(A-39)}$$

$$[i,j]_{\omega_{21}}=\frac{\Big[Cov(R_{xaj},R_{xa,m})+Cov(R_{xaf,i},R_{xa,m})-Cov(R_{xaj},R_{xaf,i})-Var(R_{xa,m})\Big]}{[\lambda_{2,i}]} \qquad \text{(A-40)}$$

$$[i,j]_{\omega_{22}}=\frac{\Big[Cov(R_{xafj},R_{xa,m})+Cov(R_{xaf,i},R_{xa,m})-Cov(R_{xafj},R_{xaf,i})-Var(R_{xa,m})\Big]}{[\lambda_{2,i}]} \qquad \text{(A-41)}$$

$$[i,j]_{\omega_{23}}=\frac{\Big[Cov(R_{aj}^{f},R_{xa,m})-Cov(R_{aj}^{f},R_{xaf,i})\Big]}{[\lambda_{2,i}]},\quad i=1,\dots,n\quad j=1,\dots,n \qquad \text{(A-42)}$$

$$[i,j]_{\omega_{24}}=\frac{\Big[Cov(R_{w}^{f},R_{xa,m})-Cov(R_{xaf,i},R_{w}^{f})\Big]}{[\lambda_{2,i}]},\quad i=1,\dots,n\quad j=1,\dots,n \qquad \text{(A-43)}$$

$$[i,j]_{\omega_{31}}=\frac{\Big[Cov(R_{xa,m},R_{ai}^{f})-Cov(R_{xaj},R_{ai}^{f})\Big]}{Var(R_{ai}^{f})},\quad i=1,\dots,n\quad j=1,\dots,m-1 \qquad \text{(A-44)}$$

$$[i,j]_{\omega_{32}} = \frac{\left[Cov(R_{xa,m}, R_{ai}^f) - Cov(R_{xafj}, R_{ai}^f)\right]}{Var(R_{ai}^f)}, \quad i=1,\ldots,n \quad j=1,\ldots,n \tag{A-45}$$

$$[i,j]_{\omega_{33}} = \frac{-Cov(R_{aj}^f, R_{ai}^f)}{Var(R_{ai}^f)}, \quad i = 1,\ldots,n \quad j = 1,\ldots,n \tag{A-46}$$

$$[i,j]_{\omega_{34}} = -\frac{Cov(R_{ai}^f, R_w^f)}{Var(R_{ai}^f)}, \quad i = 1,\ldots,n \quad j = 1,\ldots,n \tag{A-47}$$

$$[j]_{\omega_{41}} = \frac{\left[Cov(R_{xaj}, R_w^f) - Cov(R_{xa,m}, R_w^f)\right]}{Var(R_w^f)}, \quad j = 1,\ldots,m-1 \tag{A-48}$$

$$[j]_{\omega_{42}} = \frac{\left[Cov(R_{xafj}, R_w^f) - Cov(R_{xa,m}, R_w^f)\right]}{Var(R_w^f)}, \quad j = 1,\ldots,n \tag{A-49}$$

$$[j]_{\omega_{43}} = \frac{Cov(R_{aj}^f, R_w^f)}{Var(R_w^f)}, \quad j = 1,\ldots,n \tag{A-50}$$

$$[j]_{\omega_{44}} = 0.$$