Appendix A: Notations

The following notations are used to develop the model.

Indexes:

k : crop indicators, $k = 1$ for wheat, $k = 2$ for maize, $k = 3$ for sunflower

i : water usage indicator, $i = 1$ for agricultural sector, $i = 2$ for industrial sector, $i = 3$ for domestic sector, $i = 4$ for ecological sectors

Parameters:

p_i : water price set by the leader for sectoral water uses, RMB/m^3

ERW_i : economic return per unit of water consumption in sectors, $i = 1,2,3$, RMB/m^3

ERP_k : economic return from agricultural products exports, $i = 1$, where $ERP_k = ERW_k \times VW_k$, RMB/$m^3$

c_k : economic costs because of agricultural products imports RMB/kg

TC : transaction cost per unit of water resource from agricultural sector to industrial or domestic sectors RMB/m^3

μ : the irrigation coefficient, which presents the utilization effectiveness of irrigation water

A : total available area for crop planting, hm^2

ϕ_{ind} : the gross industrial output value, RMB

R_k : effective rainfall, mm

ϖ_k : crop k consumption per unit in the Hetao irrigation area, kg/person

Auxiliary variables (continuous variables)

AW : maximum volume of available water in Hetao irrigation district, m^3

PTI : price of water transfers to industrial sector, RMB/m^3

PTD : price of water transfers to domestic sector, RMB/m^3

w_k : water irrigation for crop k, /m^3

W_k represents the blue and green water components in crop k, m^3

y_k represents the crop yield per unit of irrigation area, kg/hm^2

l_k : total yield of crop k, kg

VW_k : virtual water content of crop k, m^3 kg^{-1}

A_{1k} : area allocated to crop k, hm^2

d_i : water demand of sectors, $i = 1, 2, 3, 4$, m^3

d_{1k} : water demand of crops in agricultural sector, $k = 1,2,3$, m^3

ϕ_{pop} : per capita disposable income, RMB

POP: population in the Hetao irrigation area

Decision variables (continuous variables)

X_i : initial water rights in sectors, $i = 1, 2, 3, 4$, determined by the upper-level decision maker, m^3

EM_k: quantity of products exports, determined by the upper-level decision maker, kg

IM_k: quantity of products imports from international trade, determined by the upper-level decision maker, kg

WTI : water transfer from agricultural sector to industrial sector, determined by the lower-level decision makers, m^3

WTD : water transfer from agricultural sector to domestic sector, determined by the lower-level decision makers, m^3

x_{1k} : water irrigated to crop k in the agricultural sector, determined by the lower-level decision maker, $\sum_{k=1}^{3} x_{1k} = X_1$, m^3