Water resources transfers through Chinese interprovincial and foreign food trade

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China's water resources are under increasing pressure from socioeconomic development, diet shifts, and climate change. Agriculture still concentrates most of the national water withdrawal. Moreover, a spatial mismatch in water and arable land availability—with abundant agricultural land and little water resources in the north—increases water scarcity and results in virtual water transfers from drier to wetter regions through agricultural trade. We use a general equilibrium welfare model and linear programming optimization to model interprovincial food trade in China. We combine these trade flows with province-level estimates of commodities' virtual water content to build China's domestic and foreign virtual water trade network. We observe large variations in agricultural water-use efficiency among provinces. In addition, some provinces particularly rely on irrigation vs. rainwater. We analyze the virtual water flow patterns and the corresponding water savings. We find that this interprovincial network is highly connected and the flow distribution is relatively homogeneous. A significant share of water flows is from international imports (20%), which are dominated by soy (93%). We find that China's domestic food trade is efficient in terms of rainwater but inefficient regarding irrigation, meaning that dry, irrigation-intensive provinces tend to export to wetter, less irrigation-intensive ones. Importantly, when incorporating foreign imports, China's soy trade switches from an inefficient system to a particularly efficient one for saving water resources (20 km^3/y irrigation water savings, 41 km^3/y total). Finally, we identify specific provinces (e.g., Inner Mongolia) and products (e.g., corn) that show high potential for irrigation productivity improvements.

sustainable agriculture | environmental policy | trade policy

China faces most of the major challenges to sustainable agriculture: fast socioeconomic development, rapid urbanization, and climate change along with very limited water resources and arable land per capita. Because arable land is available mainly in the water-scarce north, irrigation has become widespread, covering 45% of the country's agricultural land and accounting for 65% of national water withdrawal [Food and Agriculture Organization of the United Nations (FAO), http://fao.org/nr/water/aquastat/countries_regions/china/index.stm]. However, this development appears unsustainable because of the associated environmental impacts, such as groundwater depletion (1, 2) [in the northern provinces of Inner Mongolia and Gansu, irrigation relies on groundwater at 67% and 64%, respectively (3)] and river pollution (4). China's water resources are also strained by increasing demand from the rapidly growing industrial and residential sectors (5). Agriculture, the most water-intensive sector, may be a strong lever to reduce China's rising national water use.

The water used throughout the production process of a good is referred to as "virtual water." In the case of products containing virtual water (i.e., requiring water for their production), trade is a means of transferring water resources between regions. Moreover, domestic and international food trade may help save water at the national scale by encouraging exchanges of virtual water from highly productive countries or provinces to less productive locales, resulting in a smaller water use per unit crop grown (6). China's role in the global virtual water trade (VWT) network has been increasingly important, with its food imports contributing to 36% of the global water savings associated with international food trade (7). This significant water-saving potential of food trade needs to be explored at the national level for more policy-relevant results. The need for China to include virtual water in its national policy has been pointed out (8, 9)—especially as the country's virtual water imports will likely increase further because of projected population and economic growth (10)—and a fine-scale domestic analysis of the country's virtual water trade is key to guiding such policy planning.

China's internal VWT flows have been quantified with various methods to estimate trade [e.g., input/output (11), food balance method (12)]—required by a lack of detailed data—and commodities' virtual water content (VWC). Most of these studies have been carried out at the large regional scale (i.e., eight administrative divisions). However, given the significant spatial variability of water resources and land endowments in China (13, 14), analyzing VWT between provinces (i.e., 31 divisions) encompasses a larger portion of domestic trade and provides crucial insights for national strategies to optimize water efficiency and agricultural production.

China's interprovincial VWT may be described as a weighted and directed network, in which link direction is given by the orientation of trade (i.e., from exporting to importing province), and link weights are the volumes of virtual water traded between provinces. Interregional commodity trade [from the CHINAGRO economic model (15)] is downscaled to interprovincial trade flows

Significance

China's fast socioeconomic growth increasingly strains national water resources, notably through rising urbanization and meat demand. Agriculture is located mainly in the dry north, where irrigation largely relies on groundwater reserves. This paper analyzes the role of international and interprovincial food trade in China's national agricultural water-use and food supply. We combine a hydrological model with a trade model to quantify the volumes of irrigation and rainfall water transferred between provinces and other countries through agricultural trade. We find that China's dry, irrigation-intensive provinces tend to export food commodities to wetter places, and identify specific provinces and products showing high potential for irrigation productivity enhancements. These findings are essential to inform sound policies aimed at improving agricultural sustainability in China.

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through a linear programming optimization aimed at minimizing trade costs (*Materials and Methods* and *SI Appendix*). Interprovincial food trade volumes are then converted into virtual water volumes by using VWC estimates (16, 17), which quantify the amount of water used to produce a unit of each commodity in each province, distinguishing between two main sources of water: "green" water from direct rainfall and "blue" water from irrigation sources, such as rivers, surface reservoirs, and groundwater (following the approach in ref. 18; *Materials and Methods* and *SI Appendix*). We use the global hydrological model H08 (16, 17) to estimate crop water use at 0.5° spatial resolution before aggregating to the province level. In this study, we focus on the VWT network associated with trade of four major crops (corn, rice, soy, and wheat) and three livestock products (ruminant, pork, and poultry). These products accounted for about 93% of China's domestic food supply in 2005 [in calories (FAO, http://faostat3.fao.org)]. We find that the total volume of virtual water traded by China in 2005, domestically and internationally, was 239 $km^3 \cdot y^{-1}$, accounting for ~9% of world freshwater withdrawal for agriculture (Pacific Institute, http://worldwater.org/data.html).

In this paper, we construct and analyze China's interprovincial and foreign VWT network to address the following questions: (*i*) What is the connectivity and flow structure of China's interprovincial VWT network? (*ii*) Is China's domestic food trade efficient in terms of blue and green water resources? (*iii*) What is the role of foreign trade in China's VWT network and in the associated water savings? (*iv*) Which province or commodity might be targeted to reduce water use without decreasing current national food production levels?

Results

Virtual Water Content Heterogeneity Within China. We observe significant differences in the VWC of crops and livestock among Chinese provinces. Indeed, when averaging the provincial VWC of corn, rice, soy, and wheat on the one hand and ruminant, pork, and poultry on the other, we obtain wide ranges of values. VWC ranges from about 700 kg_{water}/kg_{crop} for crops produced in Tibet to more than 2,300 kg_{water}/kg_{crop} in Hainan province, and from about 2,000 kg_{water}/kg_{meat} for meat produced in Guangdong to nearly 5,500 kg_{water}/kg_{meat} in Inner Mongolia (Fig. 1). Moreover, the share of blue and green water sources in total VWC also varies among provinces (Figs. 1 and 2). The mean share of irrigation is about 25% in crop's VWC and 16% in livestock's VWC, but in Xinjiang, Ningxia, and Inner Mongolia, irrigation water is used predominantly for crop production (85%, 69%, and 49% of VWC from irrigation, respectively; 54% of livestock's VWC from irrigation in Ningxia). This reflects a climate with very little rainfall during the growing season. However, a few provinces, such as Chongqing and Guizhou, rely almost only on rainfall (only 2% and 3% of crop's VWC from irrigation, respectively; Fig. 1).

In addition, we observe differences in VWC among crops within the same province. In particular, soy always requires much more water than the other three main crops: rice, corn, and wheat (*SI Appendix* and Fig. 2; notice the different scale for soy and pork). For example, in Ningxia and Anhui provinces, soy requires as much as 4,000–5,000 kg_{water}/kg_{crop} whereas rice needs only 700 kg_{water}/kg_{crop} in most of China.

Virtual Water Trade. The network's flow distribution is remarkably homogeneous relative to that of the international VWT network, analyzed in the literature (7), as all provinces participate in VWT to a comparable extent. Indeed, the values of undirected node strength—VWT imports and exports of a given province—span a range of less than two orders of magnitude: (7.4×10^8; 5.6×10^{10} m^3/y) vs. (10^{11}; 10^{15} m^3/y) for the global network (7). We still identify important exporting provinces, such as Shaanxi, Shandong, and Henan (including trade of foreign goods or not) and major

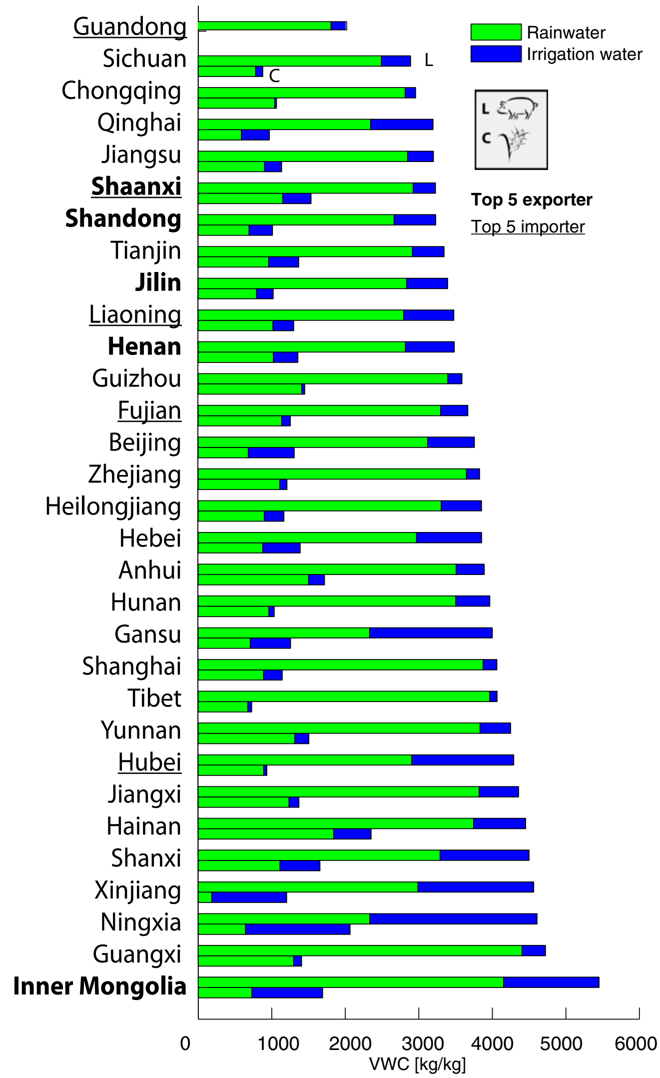

Fig. 1. Comparison across Chinese provinces of commodities' VWC (kilograms of water per kilograms of product) averaged over corn, rice, soy, and wheat for crops (C; lower bars) and pork, poultry, and ruminant for livestock (L; upper bars) in 2005. Blue and green portions of the bars indicate irrigation water and rainfall, respectively. Top exporters and importers of crops and livestock are highlighted. Note the spatial variability and the general dominance of livestock VWC (which accounts for feed provenience) vs. crop VWC.

importers, such as Shaanxi, Guangdong, and Guangxi. The largest domestic trade link is from Liaoning to Shandong: 7.5 km^3/y (mainly from soy and corn: 4.6 and 1.3 km^3/y, respectively) (Fig. 3). To be able to track the re-export of foreign goods within Chinese borders, we have distinguished foreign and domestic commodities in our optimization procedure (*Materials and Methods* and *SI Appendix*). The international harbors in Tianjin, Liaoning, and Shanghai participate in 95% of the foreign trade analyzed here and export domestically more than 60% of the foreign commodities they import (*SI Appendix*, Fig. S10). Through these domestic re-exports of foreign goods, at least 14 provinces obtain a considerable quantity of foreign food and associated virtual water. When combining international and domestic trade flows, we observe the major role of Chinese imports from abroad: VWT associated with direct international imports account for 20% of Chinese total VWT (i.e., domestic trade of local goods and direct international trade) (Fig. 3).

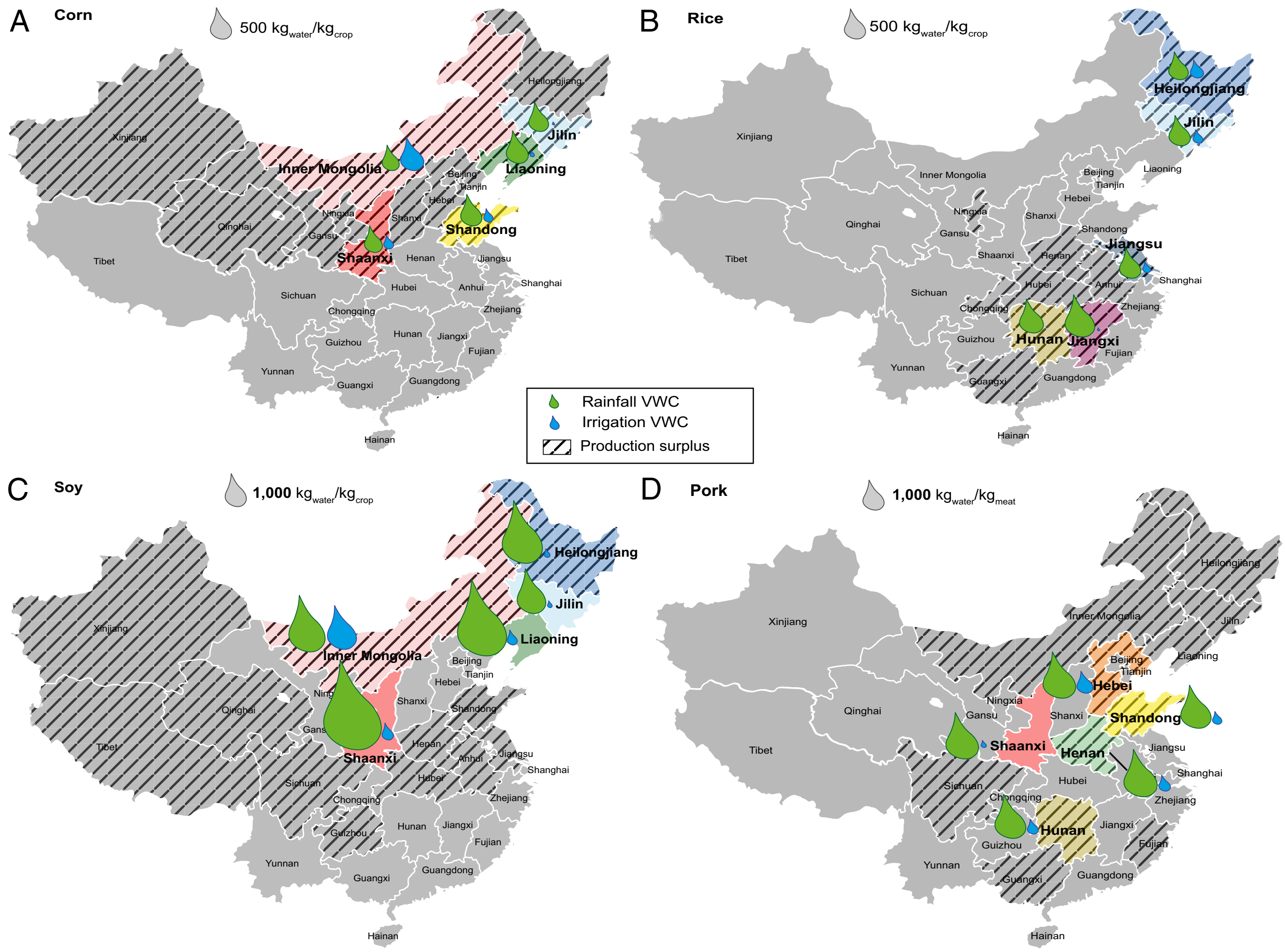

Fig. 2. VWC (kilograms of water per kilogram) of corn (*A*), rice (*B*), soy (*C*), and pork (*D*) in the top five exporting provinces in 2005 (in units of domestic commodity weight). Blue and green drops indicate the volumes of the product's VWC from irrigation sources and from rainfall, respectively (note the different scale in *C* and *D*). Hatched provinces present higher local production than consumption. Top exporting provinces are colored with the same scheme as in Fig. 3. Note the much larger water use for soy compared with other crops, and the particularly large blue-to-green water ratios in Inner Mongolia for corn and soy, in Heilongjiang for rice, and in Hebei for pork.

Water Savings. A trade relationship contributes to global water savings if it is directed from a relatively more efficient location (with lower VWC) to a relatively less efficient location (with higher VWC; *Materials and Methods*). In this case, trade saves water resources at the "global" level (i.e., the level encompassing all parties involved) compared with an autarky situation, in which each province produces what it consumes. Because we focus on China's domestic and international trade, all global water savings correspond to national savings for China, except direct exports to abroad, which are negligible (i.e., 3% of Chinese total VWT), and direct international imports, which lead to national savings for China that are even greater than global savings. Indeed, in the latter case, water savings from the global perspective are the amount of water not used in China minus the water used abroad, whereas Chinese national savings are simply the amount of water not used in China.

We find that China's domestic and international food trade leads to global water savings of 47 km^3 (Fig. 4*B*). These savings represent about 13% of Chinese irrigation water use in 2005 (FAO, http://fao.org/nr/water/aquastat/countries_regions/china/index.stm). In particular, the water savings associated with trade of soy products (41 km^3) largely dominate water savings from Chinese domestic and international VWT (Fig. 4*B*). However, domestic trade of local goods alone leads to a net loss of blue water sources: 3.1 km^3 (vs. 5.9 km^3 of green water savings) (Fig. 4*A*). Indeed, domestic wheat trade is the most efficient system (saving 7.7 km^3), but corn, pork, and soy trade (losses of 8.2 km^3, 0.9 km^3, and 0.6 km^3 of blue water, respectively) contribute to the national loss of blue water sources.

Discussion

We found that foreign trade plays an important role in the Chinese VWT network. Indeed, direct international imports correspond to 20% of the total VWT volume in 2005, and are re-exported to multiple provinces throughout the country (*SI Appendix*, Fig. S10). Ninety-three percent of these foreign virtual water imports are associated with soy-based commodities. These soy imports from abroad contribute to 87% of the total water savings associated with China's food trade, saving a significant part of Chinese blue and green water resources (21 km^3 and 20 km^3, respectively; Fig. 4*B*). Indeed, China imports soy mainly from Argentina, Brazil, and the United States, three countries that use significantly less water than China to produce soy (7), thanks to more adequate climates and advanced agricultural techniques. These savings play an even larger role (87%) in water savings from China's VWT than they do in the savings from international VWT [36% (7)].

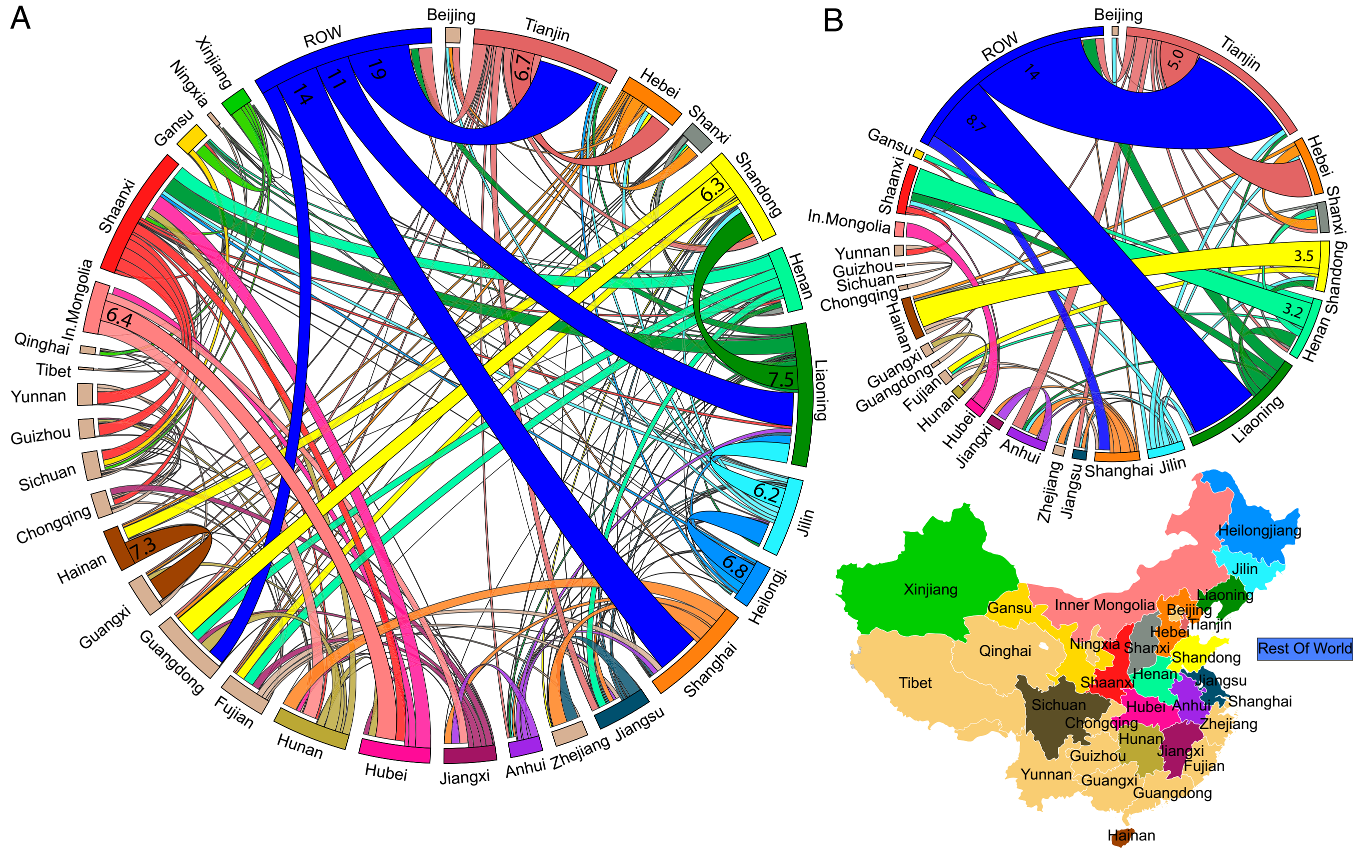

Fig. 3. Virtual water trade between Chinese provinces and the ROW (*A*), and associated positive global water savings (*B*). Numbers indicate the volume of water in cubic kilometers, and the link color corresponds to the exporting province. The map at the lower right provides a key to the color scheme. Note that the largest water-saving links are foreign imports by Tianjin and Liaoning, and exports from Shandong to Hainan. This figure was created using the network visualization software from ref. 24.

Focusing on China's domestic food trade alone, we find that the network is efficient in saving green water (5.9 km^3), but contributes to a significant loss of blue water resources (3.1 km^3). This means that irrigation-intensive provinces tend to export to relatively more rainfed ones (using less irrigation and more rainwater per unit crop). This is particularly worrisome for the country, as blue water resources (e.g., rivers, reservoirs, aquifers) are becoming increasingly scarce or polluted (1, 2). Recently, this threat to water availability and quality triggered grand water projects, such as very large dams and canals [e.g., South–North Water Transfer, which has the opposite direction as most VWT flows, but does not compensate them (12)]. However, because most of water's economic value is in the industrial and residential sectors rather than in agriculture, the government has neglected some required maintenance to irrigation systems across the country (2). Our findings support the urgency to implement water-saving means in agriculture, which might involve trade mechanisms.

The losses of blue water through domestic trade may be explained by the fact that large producers rely widely on irrigation. Indeed, some top exporting provinces have relatively low

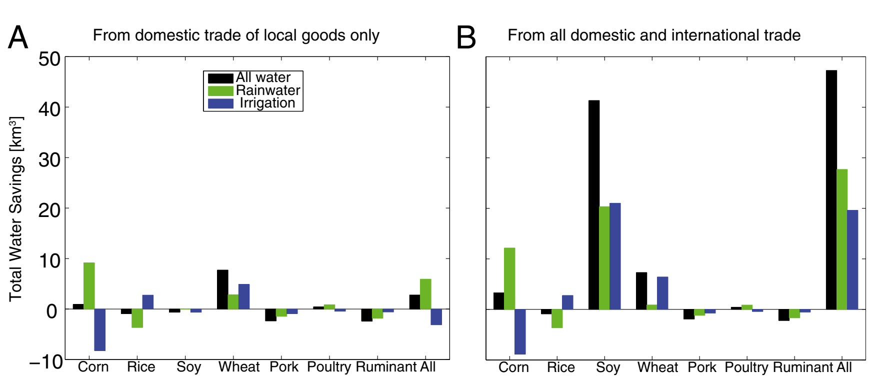

Fig. 4. Total water savings due to (*A*) domestic trade of local food only (2.8 km^3) and (*B*) all domestic and foreign food trade (47 km^3) in 2005, by product and water source. Note that domestic corn trade loses 8.2 km^3/y of blue water, whereas soy trade with foreign partners leads to significant blue and green water savings (21 and 20 km^3, respectively).

water use productivity (i.e., VWC higher than national average), such as Inner Mongolia for corn and soy production (with 58% of blue water for corn and 45% for soy), Heilongjiang for rice (with 40% of blue water), and Hebei for pork (33% of blue water) (Fig. 2). These provinces might be targets for agricultural policies that would improve water-use efficiency. However, in the case of wheat, top exporting provinces (Henan, Shaanxi, and Anhui) are relatively more water efficient than others (*SI Appendix*, Fig. S1), which is reflected in the water savings associated with China's domestic wheat trade (Fig. 4*A*).

Domestic production of corn should also be a focus for trade and agricultural policies. Although Inner Mongolia is both a top corn exporter and a province that relies largely on irrigation to produce this crop (58% of VWC from blue water; Fig. 2*A*), other top corn exporters—Jilin and Shaanxi—use much less blue water resources (10% and 29%, respectively; Fig. 2*A*). Thus, it seems that a reorganization of corn production and trade, or an improvement in water-use efficiency targeted at corn in Inner Mongolia, would be important in reducing national water use.

Both a reorganization of crop trade into a more water-efficient system (i.e., with trade flows from relatively more water-efficient provinces to less efficient provinces) and improvements in local agricultural water productivity (i.e., reduction of provincial crops' VWC) may help reduce the national water use in agriculture and increase the food supply. The latter option also carries resiliency benefits by enabling the national food supply to rely upon multiple production areas. A balance of both measures thus would be required to reduce the national water use in agriculture while avoiding an excessively geographically centralized agricultural system. Besides, possible reorganization of crop trade is limited by factors other than water, such as cropland availability and food self-sufficiency policies. However, for feed crops in particular (e.g., soybeans), foreign import restrictions—aimed at ensuring self-sufficiency—are likely to be weaker than for staple crops.

Reducing provincial VWC requires improving both water-use efficiency and crop yields. China's crop yields have improved significantly in the past decades [e.g., corn yield per unit area nearly doubled since 1983 (FAO, http://faostat3.fao.org)], but some "yield gaps" remain to be filled. In their global study, Foley et al. (19) found that although many Chinese cornfields have reached the yield ceiling, some large areas remain nutrient limited, and a few are limited by both nutrient and water. However, Foley et al. also found that most Chinese croplands have excess nitrogen (up to 100 kg/ha), suggesting that nitrogen use efficiency and distribution can be greatly improved. If higher yields are achieved this way, water use would effectively decrease. Our study suggests locations where these improvements are most needed. China's corn yields increased in the 1985–2005 period but not as fast as yields in Argentina or Brazil. Moreover, the northeastern provinces of China grow a large part of their crops for nondirect human uses, such as animal feed and biofuels. This is also the case in a few regions of the world: the midwestern United States, northwestern Europe, and some parts of Brazil and Argentina. A significant amount of food calories might be gained by diverting from these secondary uses (19), which might be another option to reduce water use.

We have shown that China's interprovincial VWT network is highly connected and presents a relatively homogeneous strength distribution ($10^8 - 10^{10}$ m^3/y). Some provinces stand out as large players, but all of them trade virtual water to a meaningful extent, so the dominance of top players is not as strong as that of the top trading countries in the international VWT network (e.g., the United States, Brazil, or China).

China's domestic food trade is efficient in terms of green water resources but inefficient regarding blue water resources. Indeed, domestic wheat trade saves both blue and green water at the national level, but domestic trade of corn loses more blue water (about 8 km^3/y).

International imports play a major role in China's VWT network, as well as in the associated savings, especially imports of soy (blue global water savings, 21 km^3/y; total global water savings, 41 km^3/y). Chinese water savings from foreign imports (at the national scale) actually are even greater than the global water savings (at the world scale), because foreign imported soy does not require any use of China's water resources.

Corn production and trade at the domestic level might be a target for improvements and might contribute significantly to reducing national water use for irrigation. Specific provinces also might be targets for improvements of water-use efficiency: provinces that export large quantities of crops while relying significantly on irrigation, such as Inner Mongolia—which is the largest corn exporter and uses a great deal of irrigation—and the northeastern provinces (e.g., Heilongjiang for rice and Hebei for pork). These assessments rely on our scientific findings, and other important agricultural policy aspects, such as land and water rights, are beyond the scope of the present study.

These findings have important implications for trade and agricultural policy in China. They constitute an essential input for designing policies (e.g., targeted investment in agricultural research and development) and provide a framework for analyzing how these policies might change China's VWT network and irrigation use in the near future.

Materials and Methods

In China's VWT network, each node represents a province or the rest of the world (ROW), and each link between a pair of nodes is directed by the direction of trade and weighted by the volume of virtual water involved in the traded commodities. The ROW node can be linked directly only with the four main trading harbor provinces of Guangdong, Shanghai, Tianjin, and Liaoning.

We use two main pieces of information to construct the VWT network: the detailed interregional food trade, downscaled to the interprovincial level, and the VWC of each commodity in all provinces. We build the VWT (kilograms of water) network by multiplying the traded volume of a specific commodity (kilograms of product) by the VWC of this commodity (kilograms of water per kilograms of product) in the province of export.

The interregional trade of agricultural products was obtained from the CHINAGRO economic model (15) for four major crops (corn, rice, soybean, and wheat) and three livestock products (ruminant, pork, and poultry). The comprehensive model is a 17-commodity, eight-region general equilibrium welfare model. It comprises six income groups per region, with farm supply represented at the level of 2,433 administrative units (virtually all counties), and accommodates for every county outputs of 28 products and 14 land use types in cropping and livestock production. Consumption is depicted at the regional level, separately for the urban and rural populations, and domestic trade is interregional (*SI Appendix*). We use simulations of 2005 trade flows, a year for which the model has been calibrated with available data.

We apply a linear programming optimization procedure (20) to downscale the interregional trade matrices to interprovincial trade matrices by minimizing the total cost of trade for each commodity (see details in *SI Appendix*). The optimization constraints ensure the consistency with interregional trade simulated by CHINAGRO and the balance of commodity supply and demand in each province (involving production, consumption, storage change, other uses, and trade flows), including foreign and domestic goods. In addition, foreign commodities appear in each province trade balance, but we allow their net export to be no larger than China's foreign import, whereas net export of domestic commodities is bounded by the local production. Finally, international trade flows through the four harbors (in Shanghai, Tianjin, Liaoning, and Guangdong) is imposed exogenously, based on reported data (21).

The VWC (kilograms of water per kilograms of product) of raw crops is defined as the evapotranspiration (ET) during a cropping period (kilograms of water per square meter) divided by the crop yield (kilograms of crop per square meter). It thus accounts for crop water consumption. The VWC of unprocessed livestock products is defined as water consumption per head of livestock (kilograms of water per head)—involving feed's VWC and drinking and cleaning water—divided by the livestock production per head (kilograms of meat per head) (see details in *SI Appendix*). The VWC value of each commodity was calculated by using provincial crop yield estimates from CHINAGRO (15) (for rainfed and irrigated lands) and ET simulated with the H08 global hydrological model (16, 17). The ET simulation used the Global Meteorological Forcing Dataset (22), which cover the whole globe at 0.5°

spatial resolution, from 1948 to 2008 at a daily interval; the average from 2002 to 2007 was used in this study. For specific crops, the rainfed and irrigated harvested area (23) were fixed circa 2000, for which detailed data are available. The VWT flows corresponding to direct international imports and to domestic trade of foreign commodities are obtained by multiplying the trade volumes by the VWC of the corresponding commodity in the ROW. We estimate this foreign VWC as an average of the VWC in China's trade partners, weighted by the share of each country in Chinese imports that year (FAO, http://faostat3.fao.org).

Global water savings (*WS*) from a trade relationship represent the amount of water that is saved (if $WS > 0$) or lost (if $WS < 0$) by trade, compared with an autarky situation. The global water savings through trade of a local commodity x from an exporting province i to an importing province j are defined (6) as

$$WS_{i,j,x} = T^{loc}_{i,j,x} \cdot \left(VWC_{j,x} - VWC_{i,x}\right), \quad [1]$$

and water savings from the trade of a foreign commodity from province i to j, because x actually is made abroad (in the ROW), are defined as

$$WS_{i,j,x} = \left(T^{for}_{i,j,x} - \sum_{k \neq i,j} T^{for}_{j,k,x}\right) \cdot \left(VWC_{j,x} - VWC_{ROW,x}\right), \quad [2]$$

where the subscripts i, j, k, and *ROW* correspond to the exporting province, the importing province, other provinces, and the ROW, respectively. $T^{loc}_{i,j,x}$ and $T^{for}_{i,j,x}$ are the volumes traded from i to j of commodity x locally or internationally produced, respectively. $VWC_{j,x}$ is the VWC of commodity x in province j, and $VWC_{ROW,x}$ is a weighted average of *VWC* of x in international trade partners. Note in Eq. **2** that only the net import of foreign goods is considered to avoid double counting due to re-export.

We compute the global water savings for all trade relationships and aggregate *WS* values by the commodity's base product (corn, rice, soy, wheat, ruminant, pork, and poultry) as follows:

$$WS_x = \sum_{(i,j)} WS_{i,j,x}, \quad [3]$$

where (i,j) corresponds to all pairs of nodes, including 31 provinces and the ROW.

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ENVIRONMENTAL SCIENCES

SUSTAINABILITY SCIENCE

Supplementary Information for: Water resources transfers through Chinese inter-provincial and foreign food trade

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The following supplementary information (SI Appendix) covers two main sections. The first section describes the materials and methods used to construct China's virtual water trade network. The second section presents in further details the results described in the printed version of the paper: "Water resources transfers through Chinese inter-provincial and foreign food trade", and includes additional tables and figures.

1 Building China's Virtual Water Trade network

In the Chinese virtual water trade (VWT) network, each node represents a province, and the rest of the world (ROW) is represented by a 32^{nd} node. Each link between a pair of nodes is directed by the direction of trade and weighted by the volume of virtual water involved in the traded commodities. We used two main pieces of information to construct the VWT network for year 2005: China's detailed inter-provincial and international food trade, and the virtual water content of each commodity in all provinces and other nations. We built China's VWT network by multiplying the traded volume of a specific commodity by the virtual water content of this commodity in the province (or foreign nation) of export:

$$VWT_{i,j,x}^{loc} = VWC_{i,x} \cdot T_{i,j,x}^{loc} \tag{1}$$

$$VWT_{i,j,x}^{for} = VWC_{ROW,x} \cdot T_{i,j,x}^{for} \tag{2}$$

where: $VWT_{i,j,x}^{loc}$ and $VWT_{i,j,x}^{for}$ (kg_{water}) are the volume of virtual water exported from province i to province j through trade of commodity x produced locally and abroad (i.e. in the ROW), respectively. $T_{i,j,x}^{loc}$ and $T_{i,j,x}^{for}$ ($kg_{product}$) are the volume of commodity x, produced locally and abroad, respectively, and exported from i to j. $VWC_{i,x}$ ($kg_{water}/kg_{product}$) and $VWC_{ROW,x}$ are the virtual water content of commodity x produced in province i and in the ROW, respectively.

In this study, we analyze individual commodity networks and the aggregated VWT network, built by summing the VWT from all selected commodities.

1.1 Food trade model

The inter-regional trade of agricultural products was obtained from the CHINAGRO general equilibrium welfare model (*Fischer et al.*, 2007) for the 4 major crops (corn, rice, soybean and wheat) and 3 livestock products (ruminant, pork and poultry) between 8 regions of China. Several commodities are grouped by base product (rice bran and milled riced are aggregated to rice, wheat bran and wheat flour to wheat, and soybean oil and cakes to soy). CHINAGRO conducted its analysis within a modeling framework that (i) represents the consumer, producer and government decisions in the various regions, (ii) accounts for transportation costs in the economy, (iii) builds the supply response on spatially explicit assessment of the resource base and its biophysical characteristics, and (iv) describes agricultural processing and supply of farm inputs. Due to this set-up, CHINAGRO is a nationwide, regionalized applied general equilibrium (AGE)-model with a great deal of geographical detail. A distinctive feature of the CHINAGRO project is that it pays due attention to the large spatial and social diversity of the country. This goal is achieved by conducting analysis at the county level, distinguishing over 2,400 of these administrative units. The model distinguishes eight regional markets, which are linked to each other and to the world market through commodity flows. Hence, this welfare model is rather large, comprising around 50,000 truly endogenous variables including prices, as well as consumption by every consumer group (including urban and rural population and three income groups) in every region, and agricultural production and input demand for every land use type (included irrigated and rainfed cropland) in every county.

1.2 Downscaling food trade to the provincial level: linear programming optimization

CHINAGRO simulates food trade between 8 Chinese regions for years 2005, 2010, 2020 and 2030. Here we analyze the VWT network in year 2005. To obtain a more detailed and more complete representation of Chinese domestic food trade, we use an optimization model to downscale the inter-regional trade to inter-provincial trade, i.e. between the 31 Chinese provinces. By doing so, we capture a significantly larger part of domestic trade flows in China, and provide insightful information to guide water-saving trade and agriculture policies.

We use a linear programming optimization procedure, aiming at minimizing the cost of inter-provincial trade (which include transaction - due to price differences - and transportation costs) under several constraints, one of which being the compatibility of optimized inter-provincial trade with inter-regional trade simulated by the CHINAGRO welfare model. The optimization procedure is as follows.
Objective: minimizing cost of inter-provincial trade,
subject to the following constraints:

- inter-provincial trade flows are positive and we impose foreign trade with 4 harbor provinces
- supply equals demand in each province, based on local production and consumption of each commodity and on net foreign and local imports
- the sum of exports from all provinces in region N to all provinces in region M equals the inter-regional export from N to M, as simulated by CHINAGRO
- net export of local goods is bounded by local production
- net export of foreign goods is either bounded by imports from abroad if these are positive, or null if no foreign import

We implement this procedure mathematically as follows:

Minimize: $TC_c = \sum_{i,j} (t^{loc}_{i,j,c} + t^{for}_{i,j,c}) \cdot tc_{i,j,c}$

subject to:

- $\forall (i,j) : t_{i,j,c} \geq 0$; $\forall i : t_{i,i,c} = 0$ and $FI_{32,i}$ for 4 harbors i (exogenous net foreign trade)
- $\forall i \in [1:31]$:
$P_{i,c} + FI_{i,c} + \sum_{j \neq i, j=1:32} (t^{loc}_{j,i,c} - t^{loc}_{i,j,c}) + \sum_{j \neq i, j=1:32} (t^{for}_{j,i,c} - t^{for}_{i,j,c}) = D^{urb}_{i,c} \cdot pop^{urb}_i + D^{rur}_{i,c} \cdot pop^{rur}_i + OU_{i,c} + \Delta S_{i,c}$
- $\forall N, M \in [1:8] : \sum_{i \in N, j \in M} t^{loc}_{i,j,c} + t^{for}_{i,j,c} = T_{N,M,c}$

- $\sum_{j \neq i, j=1:32} (t^{loc}_{i,j,c} - t^{loc}_{j,i,c}) <= P_{i,c}$
- $\sum_{j \neq i, j=1:32} (t^{for}_{i,j,c} - t^{for}_{j,i,c}) <= max(0, FI_{i,c})$

where:

- ◦ t^{loc}_c and t^{for}_c (kg_{crop}) are the unknown inter-provincial trade matrix for commodity c, produced locally and abroad (foreign), respectively,
- ◦ TC_c ($Yuan$) is the total cost of inter-provincial trade of commodity c,
- ◦ tc ($Yuan/kg$) is the inter-provincial trade cost matrix.
- ◦ Indices i, j refer to 31 provinces and indices N, M refer to 8 regions.
- ◦ $P_{i,c}$, $FI_{i,c}$, $\Delta S_{i,c}$ and $OU_{i,c}$ (kg_{crop}) are respectively province i's production, net foreign import, net stock increase and other uses of commodity c.
- ◦ $D^{urb}_{i,c}$ and $D^{rur}_{i,c}$ (kg_{crop}/cap) are province i's consumers demand per capita for commodity c, respectively from urban and rural area.
- ◦ pop^{rur}_i and pop^{urb}_i (cap) are respectively province i's rural and urban population.
- ◦ Finally, T_c (kg_{crop}) is the inter-regional trade matrix simulated by CHINAGRO, for commodity c.

The inter-provincial transport cost is obtained through a GIS based dataset of different transportation modes (rail, river, road) between the provinces capital cities (*GIS*, 2012) and the corresponding transportation costs (*NSBC*, 2006).

We solve this optimization problem for each of the 8 commodities in year 2005 using the linear programming tool embedded in MATLAB (*MATLAB*, 2010); and obtain the corresponding inter-provincial trade matrices.

1.3 Virtual Water Content estimates

Virtual water content (*VWC*, $kg_{water}/kg_{product}$) of raw crops is defined as the evapotranspiration during a cropping period divided by the crop yield:

$$VWC_{i,c} = \frac{\overline{ET}_{i,c}}{Y_{i,c}} \tag{3}$$

where $ET_{i,c,s}$ is the average evapotranspiration over the area cultivated with crop c in country i (kg_{water}/m^2) and $Y_{i,c}$ is the yield of crop c in country i (kg_{crop}/m^2).

The VWC of unprocessed livestock products (kg_{water}/kg_{meat}) is defined as the water consumption per head of livestock (including virtual water from feed, drinking and cleaning water) divided by the livestock production per head:

$$VWC_{i,l} = \frac{WC_{i,l}}{P_{i,l}} \tag{4}$$

where $WC_{i,l}$ is the water consumption per head of livestock ($kg_{water}/head$) and $P_{i,l}$ is the livestock production per head ($kg_{livestock}/head$) in country i.

WC takes into account cleaning and drinking water as well as the VWC of the feed consumed by each animal throughout its lifetime. An important part of animal feed (i.e. maize, Carbohydrate and Protein feed mixes) is traded across provinces and national boarders. Thus, we have calculated feed VWC in each province by taking into account trade flows of maize, Carbohydrate and Protein feed mixes simulated by CHINAGRO (see 1.3.2.).

To transform the VWC of raw crops into that of a processed commodity made with that crop (e.g. soybean oil), we multiplied equation 3 by $p_x c_x / r_x$, following the method of Hanasaki et al. (*Hanasaki et al.*, 2010). The price ratio p is the ratio between the price of the raw crop and that of the commodity produced from that crop. The content ratio c refers to the fraction of crop into the commodity's ingredients. The yield ratio r indicates the fraction of crop ingredient in the raw crop. The coefficients for each commodity are listed by *Konar et al.* (2011).

1.3.1 Virtual water content of crops

Virtual water content (VWC) of crops was defined as follows. The total VWC (VWCTOT kg/yr), originated from green water (VWCG) and blue water (VWCB), was expressed as

$$VWCTOT = \frac{\overline{ET}_R + \overline{ET}_I}{Y \cdot (A_R + A_I)} \tag{5}$$

$$VWCG = \frac{\overline{ET}_R}{Y \cdot (A_R + A_I)} \tag{6}$$

$$VWCB = \frac{\overline{ET}_I}{Y \cdot (A_R + A_I)} \tag{7}$$

where A_R, A_I, and Y denote harvested area of rainfed and irrigated cropland, and crop yield respectively. $\overline{ET}_R$ and $\overline{ET}_I$ are the total amount of evapotranspiration during a cropping period from rainfed and irrigated cropland respectively (kg_{water}/yr), and expressed as follows:

$$\overline{ET}_R = \sum_c \sum_{DOY=plant}^{harvest} ET_{R,c,DOY} \cdot (A_{R,c} + A_{I,c}) \tag{8}$$

$$\overline{ET}_I = \sum_c \sum_{DOY=plant}^{harvest} ET_{I,c,DOY} \cdot A_{I,c} \tag{9}$$

where $ET_{R,c,DOY}$ is daily evapotranspiration for the date DOY (day of year) of a calculating grid cell of crop c from rainfed cropland, $ET_{I,c,DOY}$ is that from irrigated land. Subscripts $plant$ and $harvest$ denote planting and harvesting date, respectively. In this study, $A_{R,c}$ and $A_{I,c}$ were derived from MIRCA2000 (*Portmann et al.*, 2010). MIRCA2000 includes harvested area for 26 crop types with the separation of irrigated and rainfed area globally circa 2000. It covers the whole globe at the spatial resolution of 5 minute. In case Y is not available (e.g. the climate is not suited for the crop), it was substituted by the national average value. $ET_{R,c}$ and $ET_{I,c}$ were simulated using the H08 hydrological model (*Hanasaki et al.*, 2008a,b) as shown in section 1.4.

1.3.2 Virtual water content of livestock

First, the VWC of feed (F_l) for livestock products l (ruminant, pork and poultry) was calculated as follows:

$$F_l = \sum_c VWC_c \cdot f_{l,c} \tag{10}$$

where VWC_c is the virtual water content of feed products c, and c designates carbohydrate feed (CH feed), protein feed (PROT feed) and maize, as defined in CHINAGRO (*Fischer et al.*, 2007). These feed products' VWC were calculated for each province taking into account the international and domestic trade simulated with CHINAGRO, and assuming the following ingredient mix: CH feed made of rice and wheat, PROT feed made of soybean cakes, rice bran and wheat bran. Then, the livestock diets from CHINAGRO are used to calculate the resulting livestock VWC. The numbers are shown below, and are derived from the proportion of national averaged feed consumption of CHINAGRO.

Ingredients of concentrated fodder:

Share (in %)	Beef	Pork	Chicken
Maize	14	48	48
Soy	19	16	16
Rice	7	17	17
Wheat	13	13	13
Others	47	6	6

Note that VWC for other ingredients was neglected, since it is considered substantially smaller than the VWC of crops. However, for raised livestock, VWC can be expressed as

$$VWC_l = a_l \cdot F_l + b_l \tag{11}$$

where a_l is per product feed consumption, and b_l is water consumption other than feed. In the case of grazed cattle, VWC_{graze} can be expressed as,

$$VWC_{graze} = a_{graze} \cdot VWC_{pasture} \tag{12}$$

Where a_{graze} is per product pasture consumption and $VWC_{pasture}$ is VWC of pasture. Water use other than the growth of pasture is neglected for grazed cattle.

1.4 H08 hydrological model

H08 is a global water resources model which deals with both natural hydrological processes and major human activities related to water use. Complete model formulations and validation results are explained by Hanasaki et al. (*Hanasaki et al.*, 2008a,b). H08 consists of six sub-models: land surface hydrology, river routing, crop growth, reservoir operation, water withdrawal, and environmental flow requirement sub models. The land surface hydrology sub model is based on a bucket type model (*Manabe*, 1969; *Robock*, 1995). A simple subsurface flow process, which is similar to the process used by *Gerten et al.* (2004), is included. The effective flow velocity is set at globally uniform 0.5 m/s. The crop growth sub model is based on SWIM model (*Krysanova et al.*, 2000). The model uses a concept of phenological crop development model based on daily accumulated heat units, Monteith's approach (*Monteith*, 1977) for potential biomass, stress factors for water, temperature, and nutrients (*Krysanova et al.*, 2000). In this simulation, the crop growth sub model is mainly used to estimate cropping period globally.

First using the land surface hydrology model, evapotranspiration from rainfed cropland ($ET_{R,c,DOY}$) was estimated globally at daily interval, assuming that all of the grid cells contained cropland. Second, using the same model, evapotranspiration from irrigated cropland ($ET_{I,c,DOY}$) was estimated similarly, assuming that all of the grid cells contained irrigated cropland. In irrigated cropland, the soil moisture is kept higher than 75% of field capacity throughout a year with unrestricted water supply. Third, using the crop growth model, planting and harvesting date of four crops was estimated globally. We assumed that all of four crops were sown in all of the grid cells (e.g. rice is sown even in arctic). We repeated simulations for 365 times by shifting planting date from January 1 to December 31. The crop growth model judges the suitability of climate condition for crop growth at a daily interval. It kills crops when and where its climate condition is not suited (e.g. rice sown on January 1 in arctic is killed). It calculates the growth of crops at daily interval. When the crop is matured, the date and crop yield is recorded. After finishing 365 simulations, the crop yield of twenty-one days running mean was calculated for each planting date, and the date that produced the maximum crop yield was assumed as planting date. The performance of this simulation has been evaluated in the work of *Hanasaki et al.* (2008b).

In each 0.5° by 0.5° grid cell, the crop-wise rainfed and irrigated harvested area (*Portmann et al.*, 2010) were fixed circa year 2000, for which detailed data is available (5 minute spatial resolution). Meteorological information is input from the GMFD (*Sheffield et al.*, 2006), with precipitation, temperature, relative humidity and radiation averaged around year 2005 (2003-2007).

To ensure consistency between the crops VWC values estimated by the H08 model and the trade volumes obtained from the CHINAGRO model, which produces province-level crop production estimates, crop yield per area sown from CHINAGRO was used as the crop yield per area (Y) in calculations of province-level crops VWC (Equation 3). Thus, each crop's yield per area sown (irrigated and rainfed cropland, *Fischer et al.* (2007)) is used to scale crop yield up to the province level.

2 Results

2.1 Virtual Water Content across China

The virtual water content (or water footprint) of each commodity varies significantly across provinces of China. Moreover, the share of different water resources, i.e. green water (rainfall) and blue water (irrigation), also changes from province to province. We analyze each sub-network (VWT network associated with trade of a specific commodity) separately and find that some major exporters use more water than others (higher crop VWC) to produce the same commodity, and sometimes even larger amounts of blue water (Tables S1-S7, Fig S1 and S2). This is the case for corn and soy production in Inner Mongolia (Tables S1 and S3), for rice production in Heilongjiang and Jilin (Table S2), and for pork in Hebei (Table S6).

2.2 Inter-provincial Virtual Water Trade from major crops and livestock in 2005

When analyzing the complete VWT network (build by summing individual commodity networks), we find that all provinces participate in the trade with considerable importance. Indeed, the range of VWT volumes associated with each province (node's strength, i.e. VW imports and exports of a province) is relatively narrow $[10^8 : 10^{10}]$ compared to the range observed in the international VWT network $[10^5 : 10^{11}]$. We still identify important exporters and importers (Tables S8, S9) and trade relationships (Table S10). When analyzing VWT networks associated with each specific commodity, we observe different patterns (Fig S3-S9), with more heterogeneity that in the complete network. This makes sense since some provinces might be specialized in one product and not produce much of others. We observe the importance of international imports of soy-based commodities, including soybean oil, and soybean cakes for animal feed (Fig S5). Virtual water flows associated with international trade and domestic trade of foreign commodities are shown on Figure S10. We also observe the very localized production of rice in a few neighboring provinces (Fig S1 and S4). Top exporters and importers are shown in Tables S8-9, and shown broken down by product in Tables S1-7. Top VWT links are also shown in Table S10.

2.3 Water savings from major crop and livestock inter-provincial trade in 2005

Considering VWT associated with the *domestic* trade of local wheat, rice, corn, soy, ruminant, pork and poultry, China inter-provincial trade leads to water savings of 2.8 km^3. As compared to a provincial autarky situation, 5.9 km^3 of rainfall water are saved, but 3.1 km^3 of irrigation water (drawn from rivers, reservoirs or subsurface aquifers) are lost (see Fig 4-a). We show the relative role of each exporting province in these national water savings and losses in Tables S12 and S13.

The trade of wheat is the most efficient, saving both blue and green water resources, 7.7 km^3 in total. Inter-provincial trade of corn shows the largest gap between green water savings (9.1 km^3) and blue water loss (8.2 km^3). This suggests that major corn exporters rely more on irrigation for corn production than their importing partners do, but use less rainfall water than these partners would. With much smaller volumes of water involved, domestic trade of poultry also saves green water (0.8 km^3) and loses blue water (0.4 km^3). The pattern is the opposite for rice trade, which saves blue water resources (2.8 km^3) while losing green water (3.7 km^3). Trade of local soy, ruminant meat, pork are inefficient for all sources of water, losing 0.006, 1.8 and 1.4 km^3 of green water, and 0.6, 0.6 and 0.9 km^3 of blue water, respectively.

Considering VWT associated with the *domestic and international* trade of local and foreign wheat, rice, corn, soy, ruminant, pork and poultry, China inter-provincial trade leads to water savings of 47 km^3. As compared to a provincial autarky situation, 28 km^3 of rainfall water and 20 km^3 of irrigation water (drawn from rivers, reservoirs or subsurface aquifers) are saved (see Fig 4-b).

Most products trade show virtually unchanged water savings and losses compared to the domestic situation, except soy trade. Indeed, the trade of soy becomes the most efficient system, saving both blue and green water resources, 41 km^3 in total.

Top water savings trade relationships are shown in Table S11.

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Supporting Figures and Tables

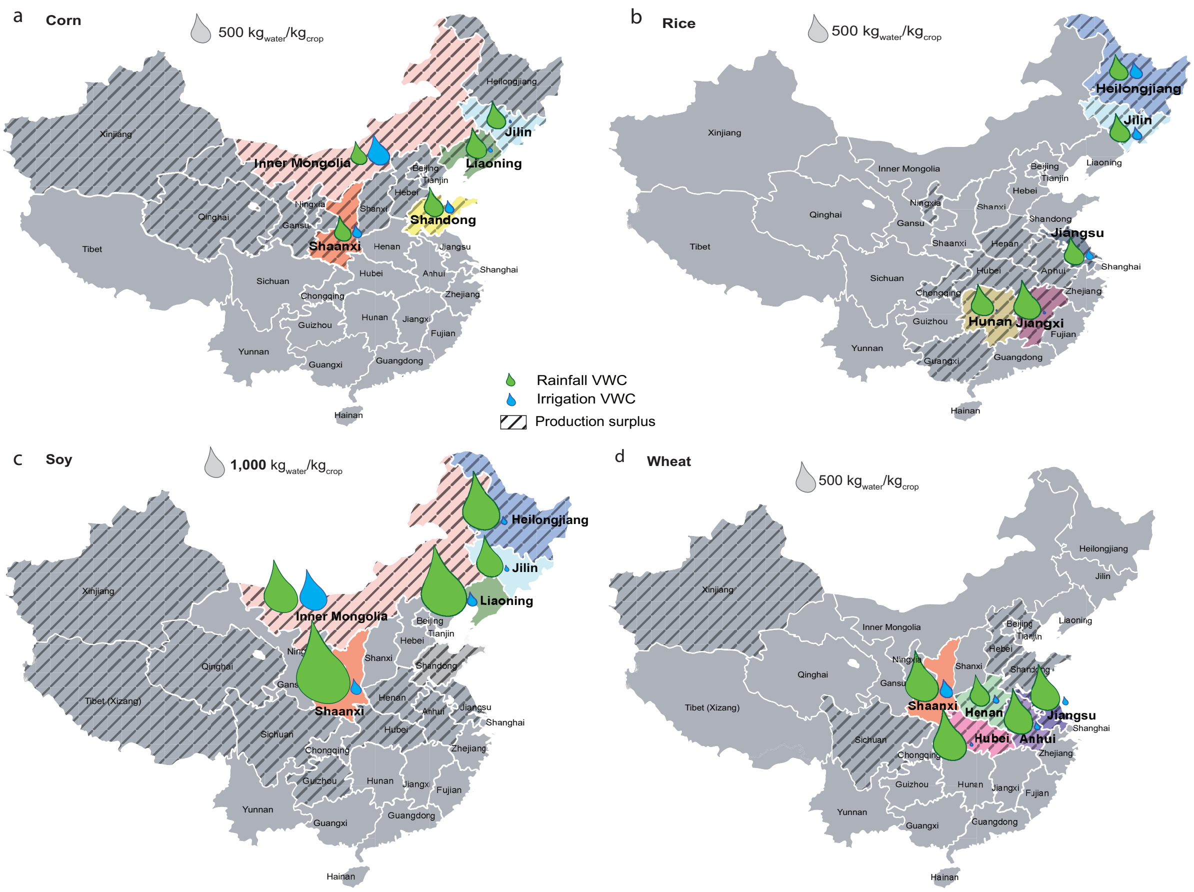

Fig. S1 Virtual Water content (VWC) of Corn, Rice, Soy and Wheat in the top 5 exporting provinces (in units of domestic commodity weight) in 2005. Blue and green drops indicate the volumes of VWC from irrigation sources and rainfall, respectively. Hatched provinces present higher local production (in weight) than consumption.

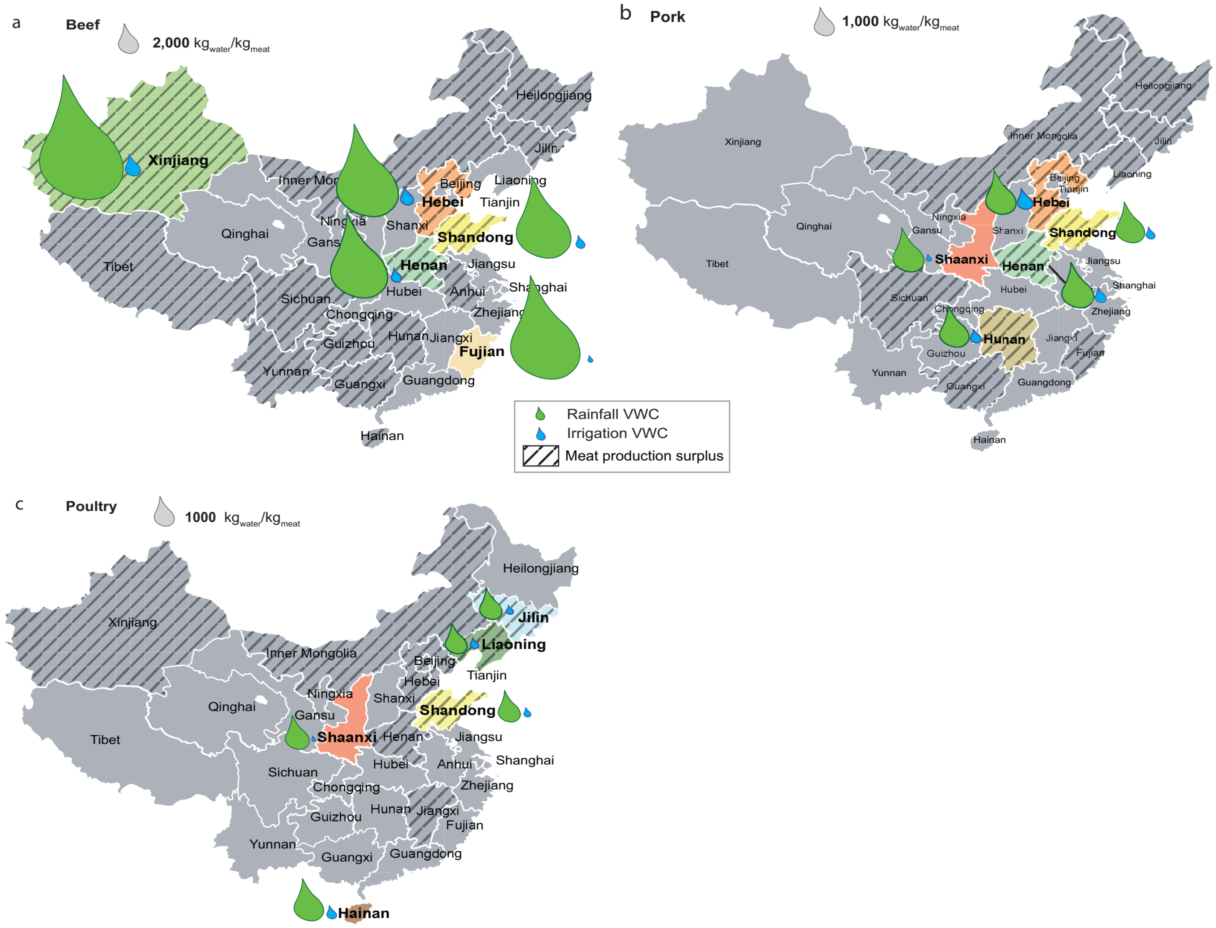

Fig. S2 Virtual Water content (VWC) of Ruminant, Poultry and Pork in the top 5 exporting provinces (in units of domestic commodity weight) in 2005. Blue and green drops indicate the volumes of VWC from irrigation sources and rainfall, respectively. Hatched provinces present higher local production (in weight) than consumption.

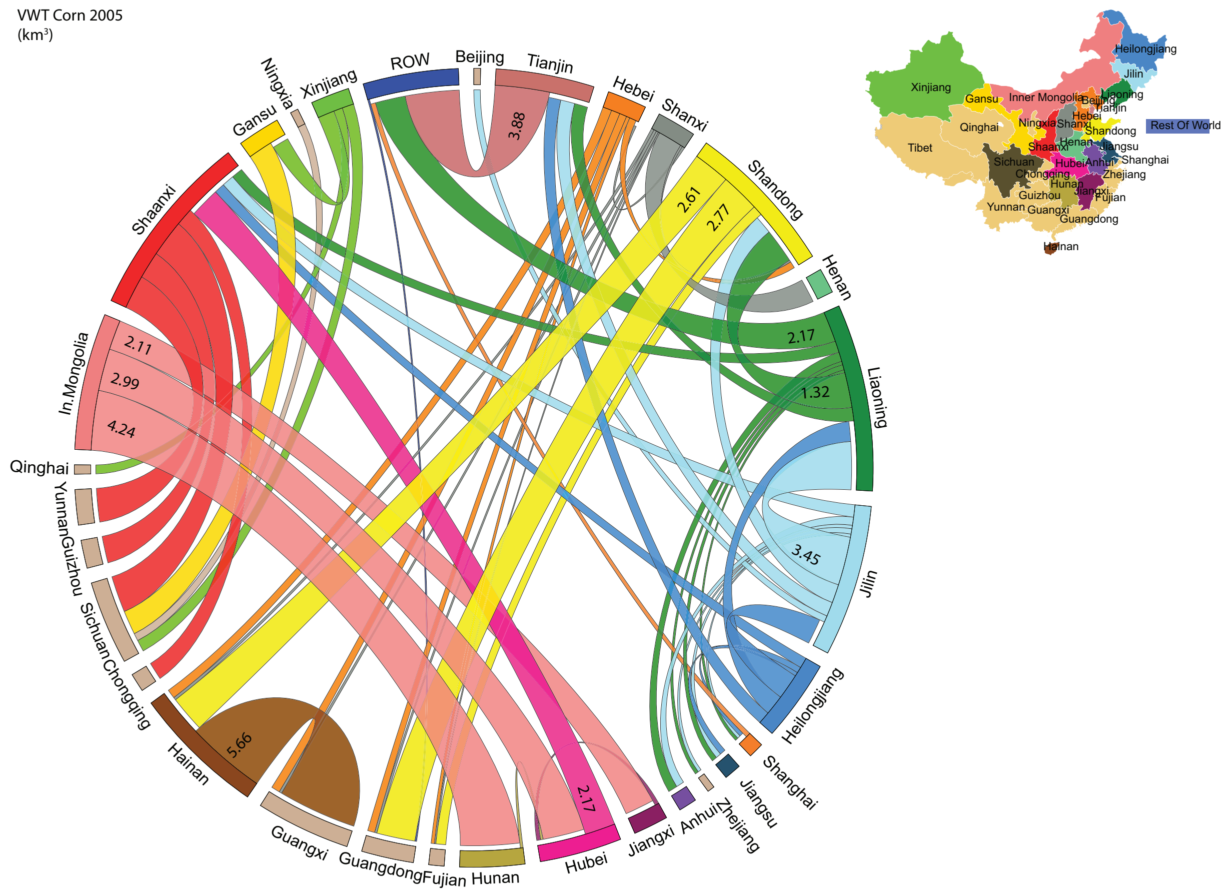

Fig. S3 VWT associated with corn.

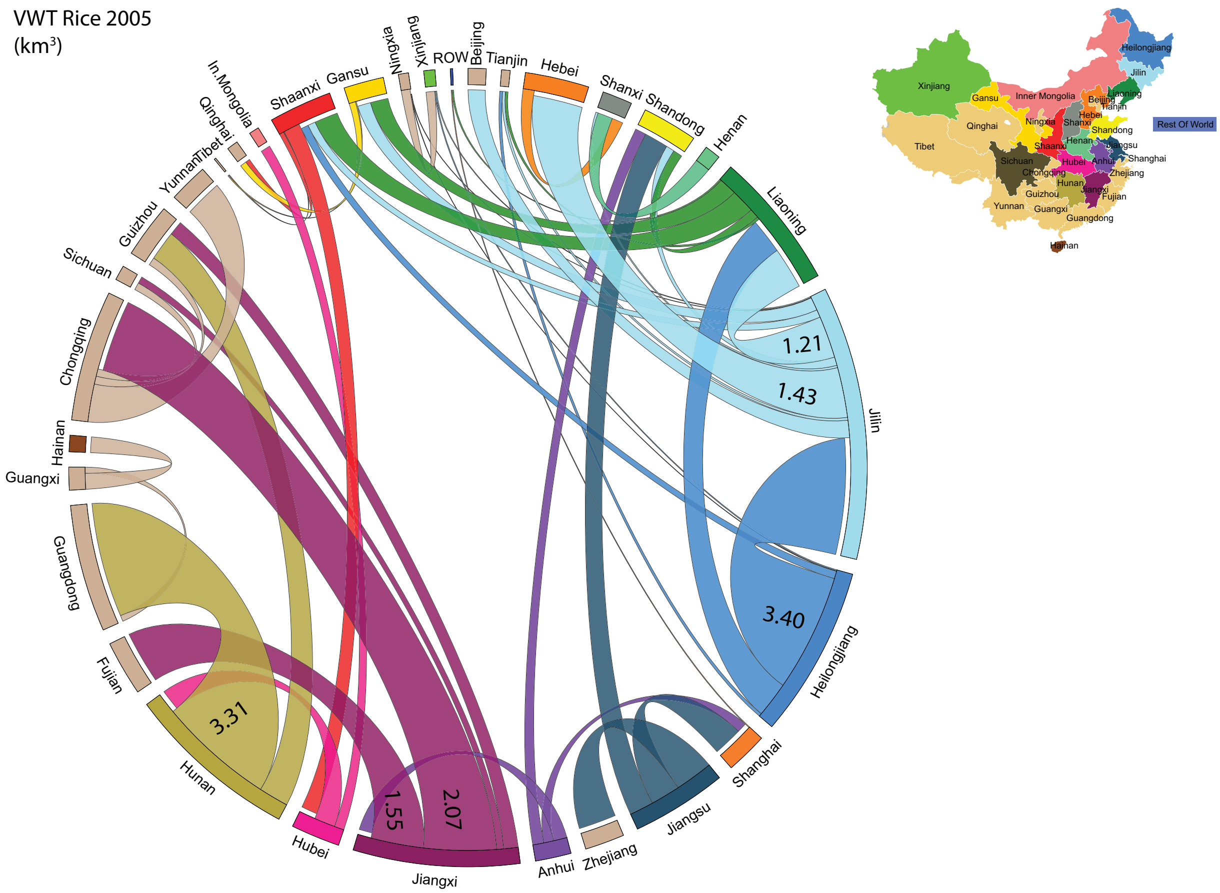

Fig. S4 VWT associated with rice.

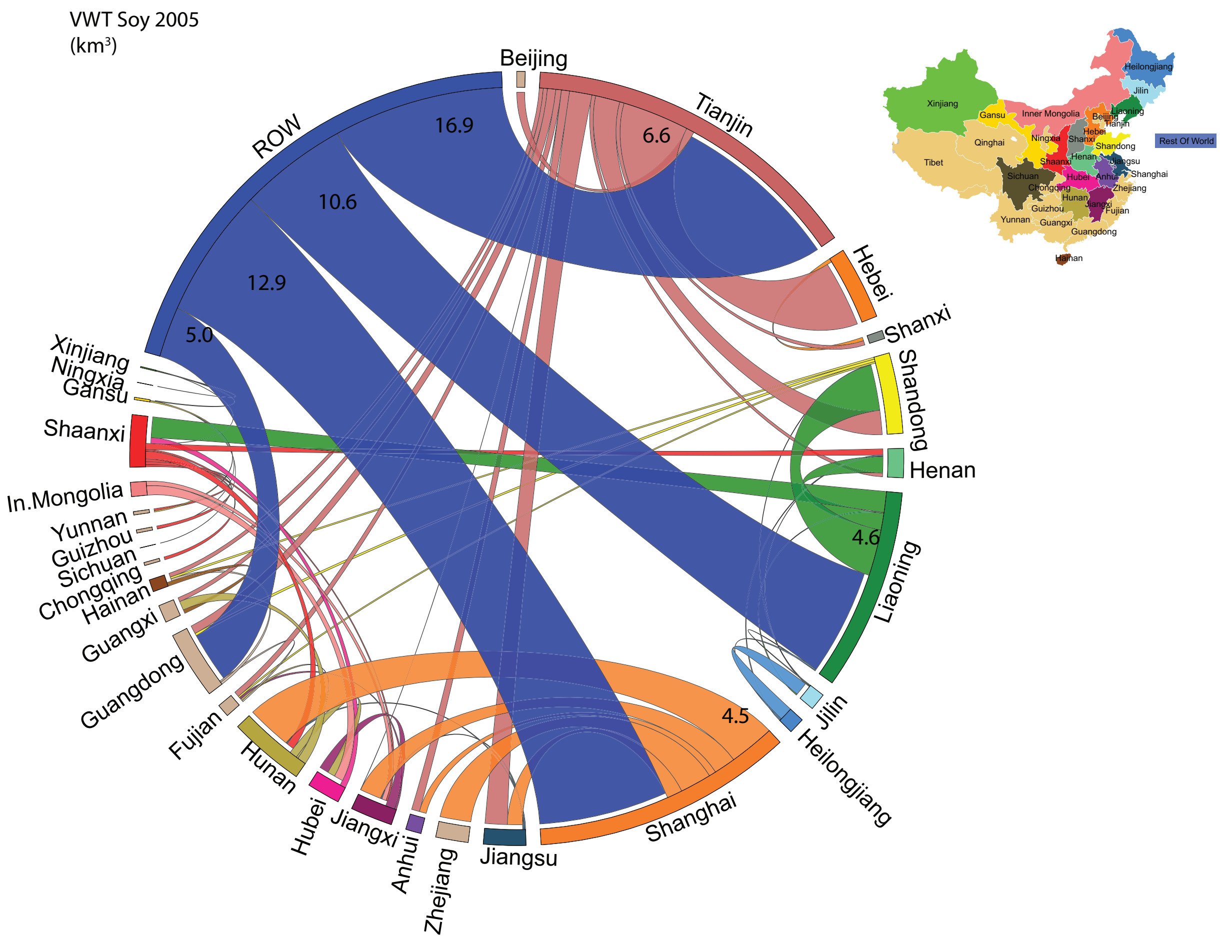

Fig. S5 VWT associated with soy.

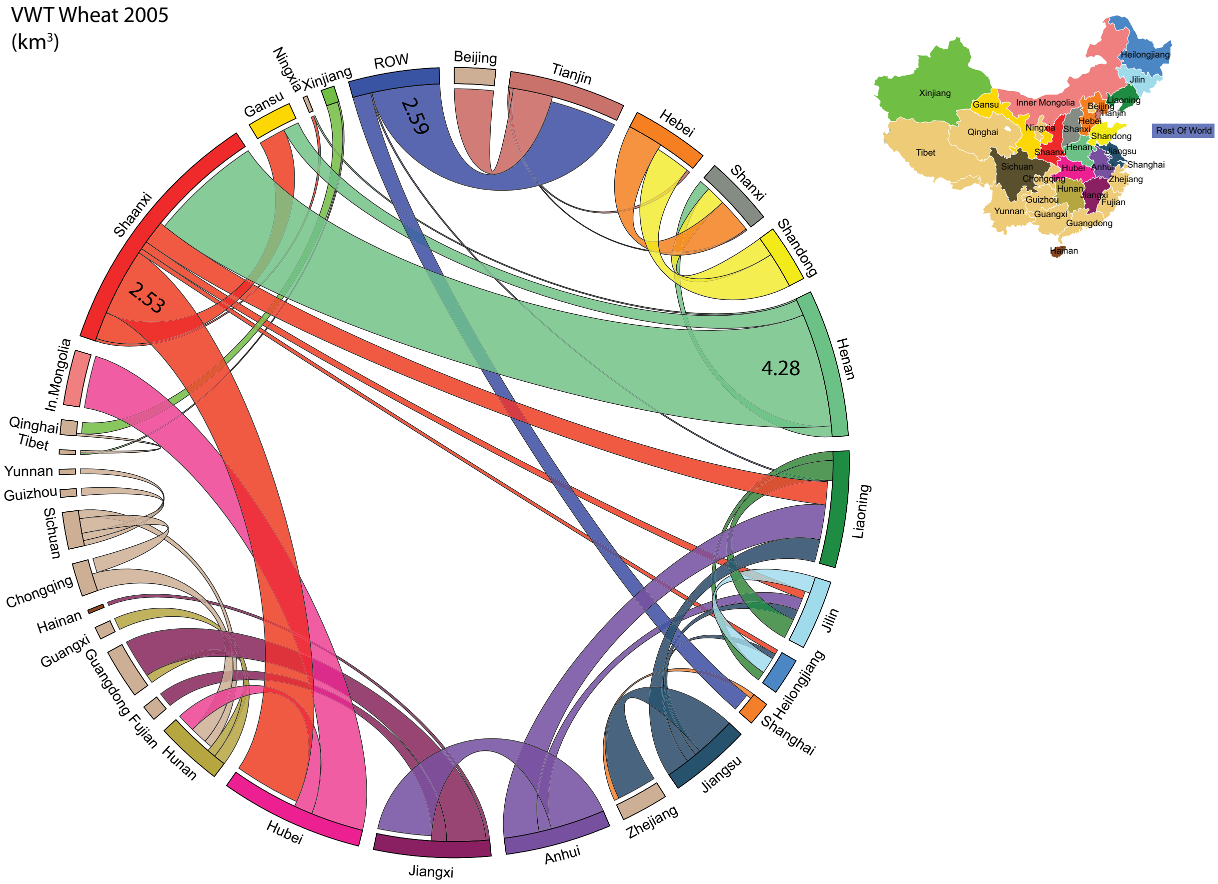

Fig. S6 VWT associated with wheat.

VWT Pork

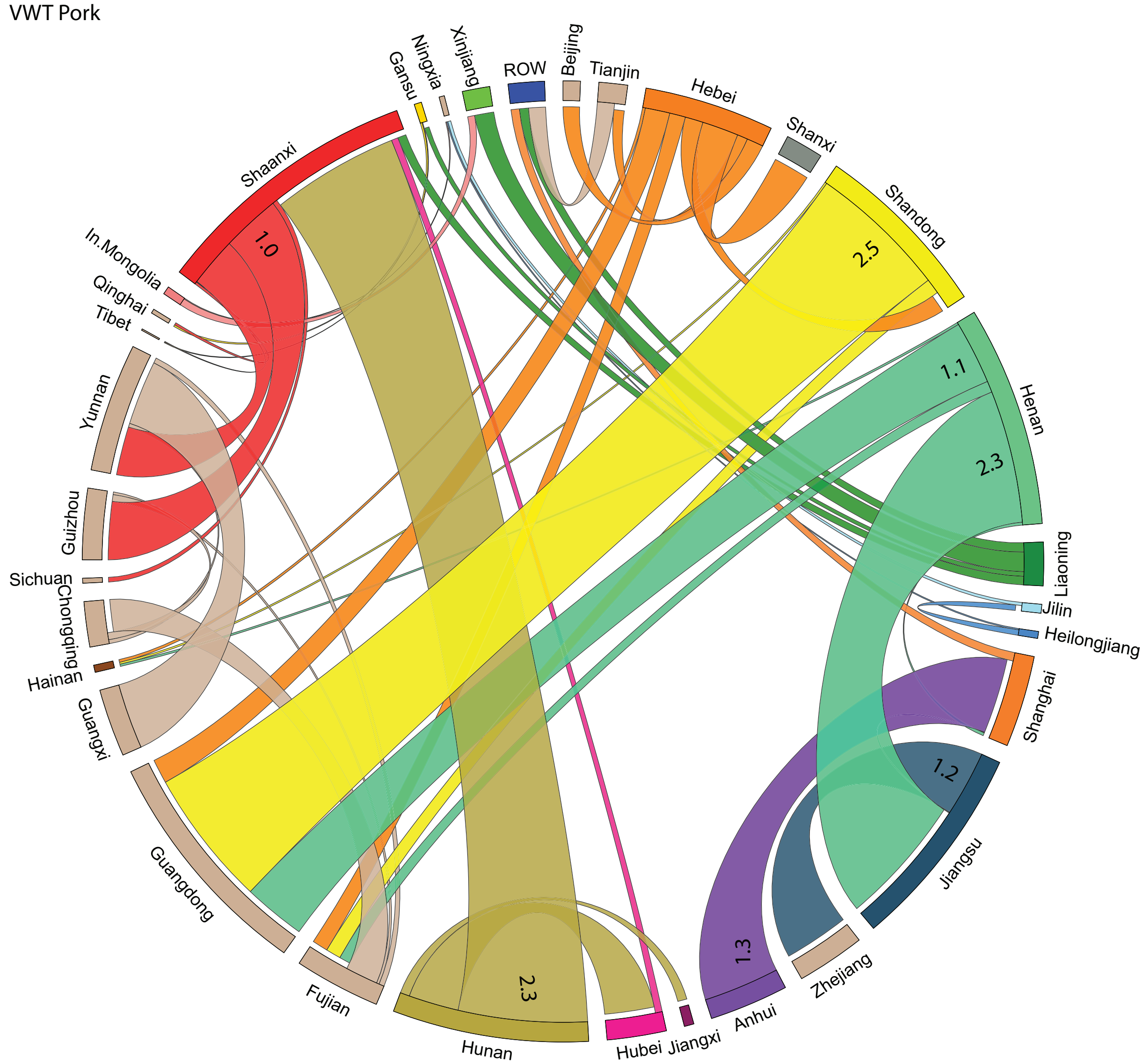

Fig. S7 VWT associated with pork.

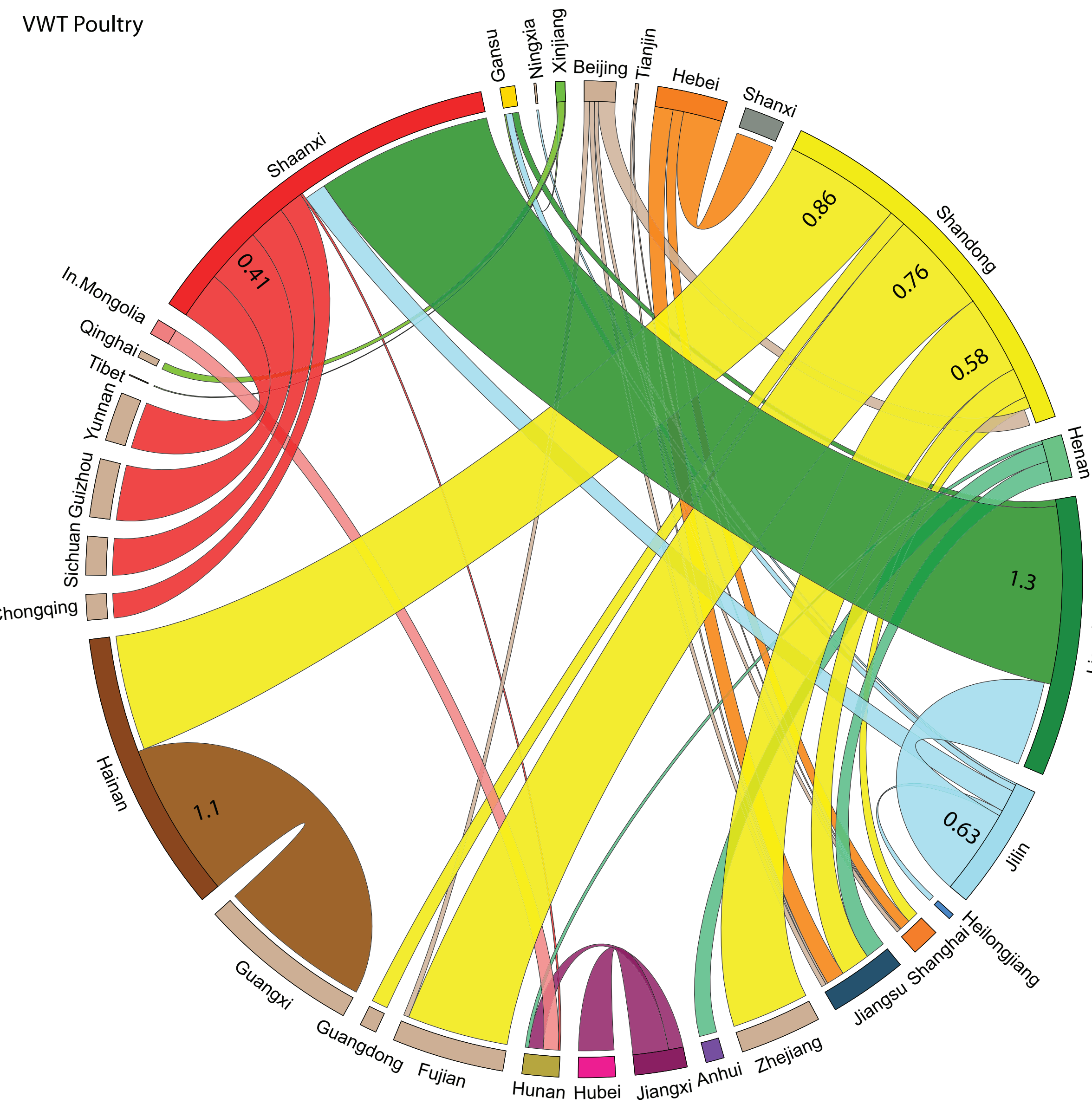

Fig. S8 VWT associated with poultry.

VWT Ruminant Meat

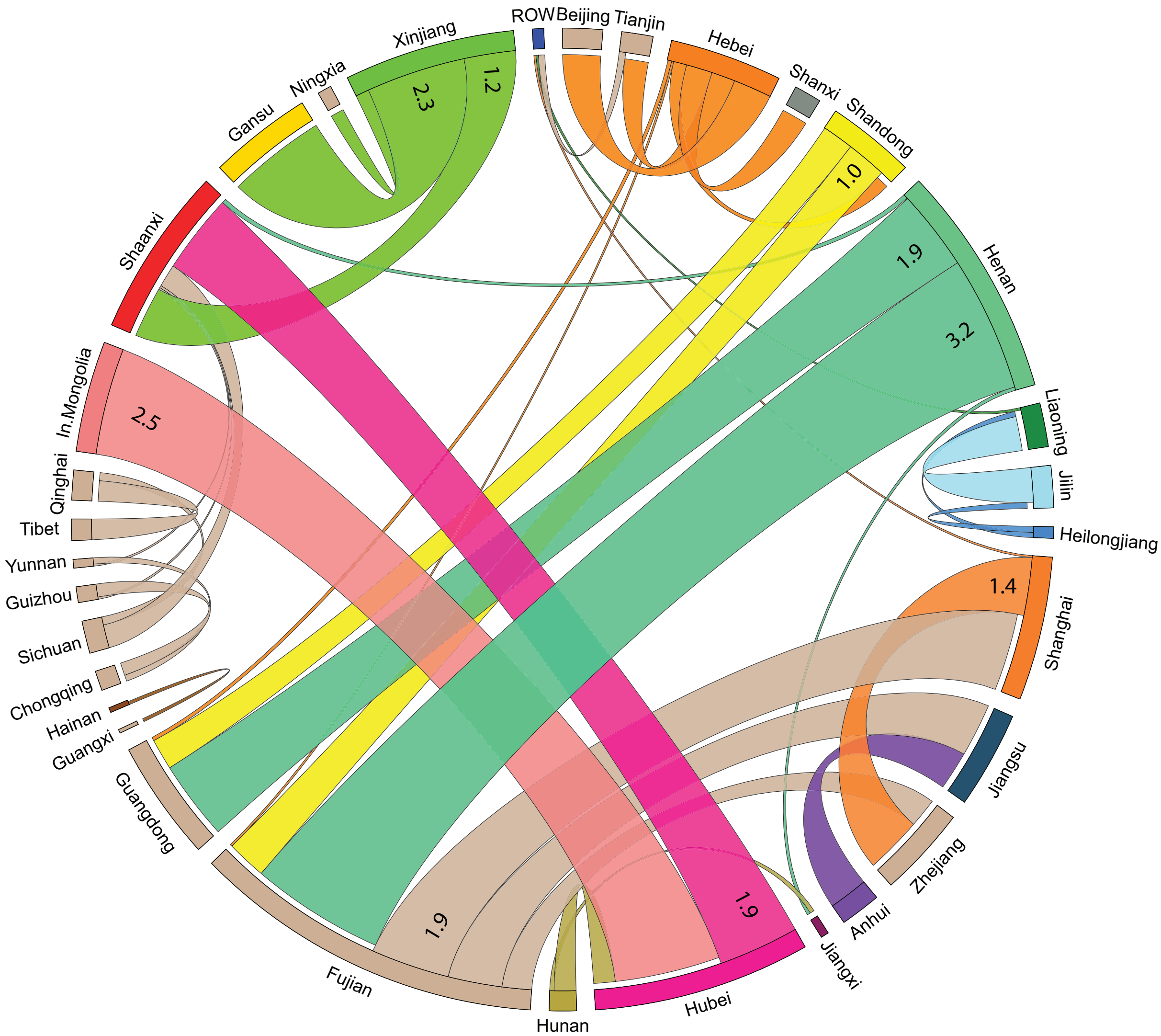

Fig. S9 VWT associated with ruminant meat.

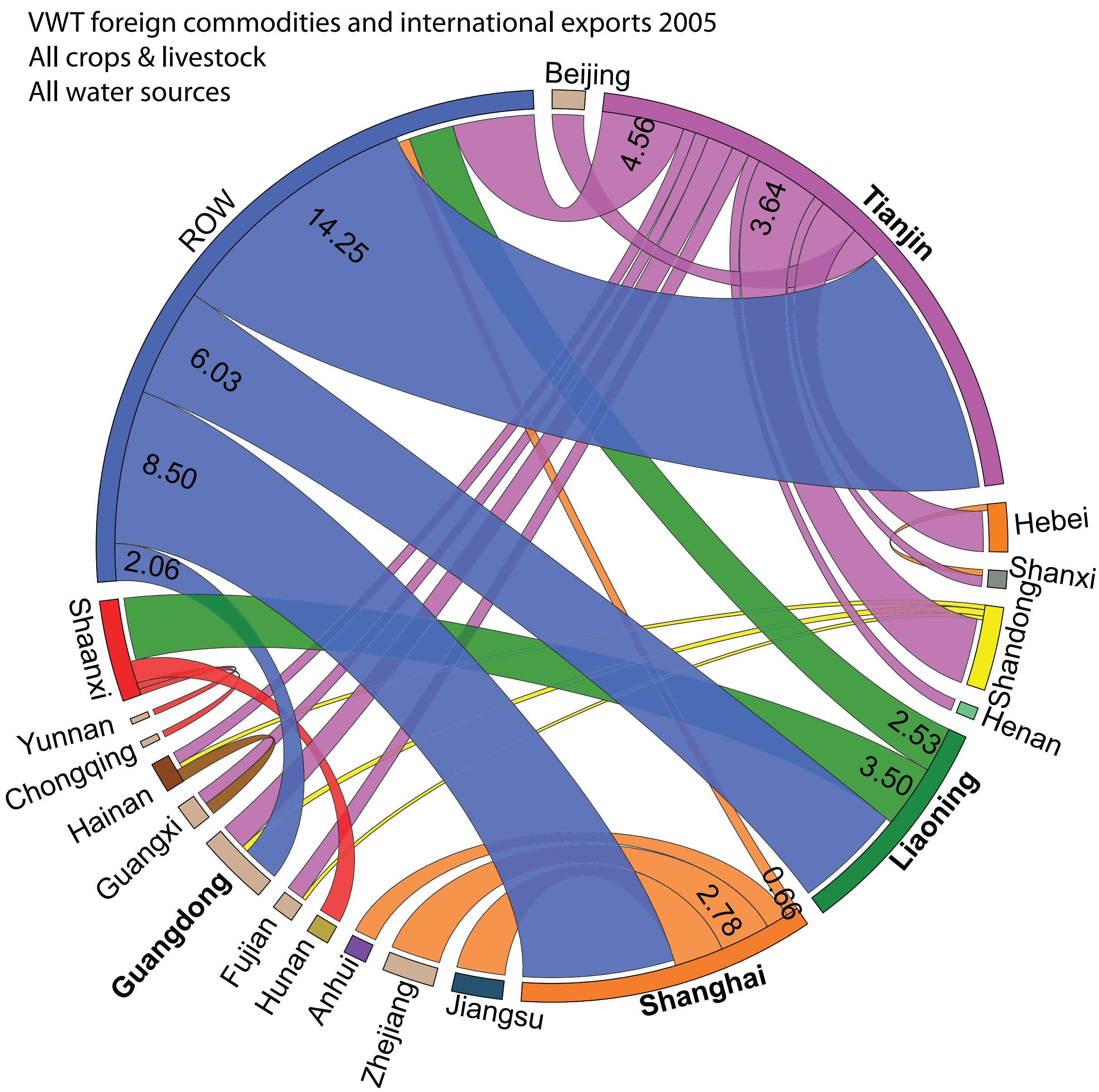

Fig. S10 VWT associated with direct international trade (exports from harbors to the ROW, imports from the ROW to harbors) as well as with *domestic re-export of foreign commodities*.

Rank	Top exporter corn	VWC (kg_{water}/kg_{crop})	green VWC	blue VWC
1	Inner Mongolia	955	405	550
2	Jilin	519	467	52
3	Shaanxi	843	598	245
4	Shandong	725	503	222
5	Liaoning	621	520	101

Table S1. Virtual water content (VWC) of corn for top corn exporting provinces (in units of domestic commodity weight), indication of green and blue water resources portions. *The blue and green VWC might not exactly sum up to total due to rounding of values.*

Rank	Top exporter rice	VWC (kg_{water}/kg_{crop})	green VWC	blue VWC
1	Heilongjiang	731	607	124
2	Hunan	703	668	35
3	Jiangxi	963	880	83
4	Jilin	519	467	52
5	Jiangsu	916	749	167

Table S2. Virtual water content of rice for top rice exporting provinces(in units of domestic commodity weight), indication of green and blue water resources portions.

Rank	Top exporter soy (domestic)	VWC (kg_{water}/kg_{crop})	green VWC	blue VWC
1	Heilongjiang	2169	1899	270
2	Inner Mongolia	3093	1714	1379
3	Liaoning	2799	2323	476
4	Shaanxi	3261	2727	534
5	Jilin	1575	1355	220

Table S3. Virtual water content of soy for top soy exporting provinces (in units of domestic commodity weight), indication of green and blue water resources portions.

Rank	Top exporter wheat	VWC (kg_{water}/kg_{crop})	green VWC	blue VWC
1	Henan	653	514	139
2	Shaanxi	1149	831	318
3	Anhui	879	743	136
4	Jiangsu	888	745	143
5	Hubei	905	837	68

Table S4. Virtual water content of wheat for top wheat exporting provinces (in units of domestic commodity weight), indication of green and blue water resources portions.

Rank	Top exporter ruminant meat	VWC (kg_{water}/kg_{meat})	green VWC	blue VWC
1	Henan	6669	5663	1006
2	Xinjiang	9868	8336	1532
3	Fujian	7404	6920	484
4	Hebei	7468	6174	1293
5	Inner Mongolia	11308	10424	884

Table S5. Virtual water content of ruminant meat for top ruminant meat exporting provinces (in units of domestic commodity weight), indication of green and blue water resources portions.

Rank	Top exporter pork	VWC (kg_{water}/kg_{meat})	green VWC	blue VWC
1	Henan	2127	1575	552
2	Hunan	1981	1465	516
3	Shandong	1882	1435	447
4	Hebei	2303	1542	763
5	Shaanxi	1794	1543	250

Table S6. Virtual water content of pork for top pork exporting provinces (in units of domestic commodity weight), indication of green and blue water resources portions.

Rank	Top exporter poultry	VWC (kg_{water}/kg_{meat})	green VWC	blue VWC
1	Shandong	1457	1107	350
2	Liaoning	1475	1077	398
3	Shaanxi	1389	1192	196
4	Hainan	1973	1484	489
5	Jilin	1462	1120	342

Table S7. Virtual water content of poultry for top exporting provinces (in units of domestic commodity weight), indication of green and blue water resources portions.

Rank	Top exporter	VWE (km^3)
1	Shaanxi	19.6
2	Liaoning	18.9
3	Tianjin	17.7
4	Shandong	15.9
5	Henan	15.1

Table S8. Top virtual water exporters (includes foreign commodities).

Rank	Top importer	VWI (km^3)
1	Shaanxi	20.6
2	Guangdong	16.7
3	Shandong	14.0
4	Hubei	13.4
5	Hunan	12.2

Table S9. Top virtual water importers (includes foreign commodities).

Rank	Top link	VWT (km^3)
1	ROW to Tianjin	19
2	ROW to Shanghai	14
3	ROW to Liaoning	11
4	Liaoning to Shaanxi	7.5
5	Hainan to Guangxi	7.3

Table S10. Most important trade relationships in terms of VWT (virtual water trade) volume (includes foreign commodities).

Rank	Top link	WS (km^3)
1	ROW to Tianjin	14
2	ROW to Liaoning	8.7
3	Tianjin to Hebei	5.0
4	Shangdong to Hainan	3.5
5	Henan to Shaanxi	3.2

Table S11. Most important trade relationships in terms of WS (water savings) volume (includes foreign commodities)).

Exporter	WS blue (m^3)
Beijing	-2.10e+07
Tianjin	1.64e+07
Hebei	-6.58e+08
Shanxi	3.51e+07
Shandong	-9.00e+08
Henan	1.28e+09
Liaoning	1.94e+09
Jilin	3.62e+09
Heilongjiang	-1.72e+08
Shanghai	-8.28e+06
Jiangsu	1.42e+08
Zhejiang	1.64e-01
Anhui	7.86e+08
Jiangxi	-3.44e+08
Hubei	3.03e+09
Hunan	-1.93e+07
Fujian	-1.53e+08
Guangdong	3.33e+07
Guangxi	2.10e+08
Hainan	-1.13e+09
Chongqing	5.90e+08
Sichuan	-1.70e+07
Guizhou	-1.63e+06
Yunnan	-8.03e+06
Tibet	4.26e+07
Qinghai	-2.80e+07
InnerMongolia	-5.38e+09
Shaanxi	-2.66e+09
Gansu	-1.16e+09
Ningxia	-4.02e+08
Xinjiang	-1.81e+09

Table S12. Blue water savings associated with domestic exports of local goods, by exporting province, for all crops and livestock commodities.

Exporter	WS green (m^3)
Beijing	1.03e+07
Tianjin	-1.81e+07
Hebei	9.43e+08
Shanxi	7.83e+08
Shandong	1.74e+09
Henan	2.58e+09
Liaoning	2.97e+08
Jilin	1.35e+09
Heilongjiang	-6.22e+08
Shanghai	-1.35e+08
Jiangsu	6.65e+08
Zhejiang	5.93e-03
Anhui	3.73e+08
Jiangxi	-2.07e+09
Hubei	-9.12e+08
Hunan	-3.46e+09
Fujian	3.81e+08
Guangdong	1.56e+08
Guangxi	7.77e+06
Hainan	-1.43e+09
Chongqing	4.50e+05
Sichuan	9.51e+08
Guizhou	-5.54e+07
Yunnan	-4.95e+07
Tibet	-1.85e+08
Qinghai	1.44e+07
InnerMongolia	2.22e+09
Shaanxi	1.46e+09
Gansu	6.90e+08
Ningxia	2.68e+08
Xinjiang	-2.00e+07

Table S13. Green water savings associated with domestic exports of local goods, by exporting province, for all crops and livestock commodities.