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# Cotton and Hydropower in Central Asia

## How Resource Competition Affects Trade

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**Christine Arriola, Jim Hansen, and Stephen MacDonald**

## Abstract

As growing populations demand more electric power and the need for low-emission energy sources intensifies, interest has risen in hydroelectric power (hydropower) as an alternative to carbon-based sources. However, hydropower's demand for water resources is pushing up against the needs of agricultural irrigation. Hydropower is a feasible energy source only in certain regions of the world, and it accounts for only about 2 percent of the world's energy supply. But its interaction with irrigated agriculture—for instance, through competition for water or resource-sharing agreements—can generate large effects, from local to international. In this report, we approach the topic of water competition between the energy and agriculture sectors from a global perspective. To show why this perspective should matter to policy makers, we present a case study of cotton production in Central Asia in which we combine high-resolution geographic information system (GIS) data covering crops and river basins with a partial equilibrium agricultural trade model to simulate the international trade effects of different water policy scenarios.

**Keywords:** water, agriculture, energy, hydropower, cotton, Central Asia

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## About the Authors

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# Summary


## What Is the Issue?

As growing populations demand more electric power and the need for low-emission energy sources intensifies, interest has risen in hydroelectric power (hydropower) as an alternative to carbon-based sources. However, hydropower's demand for water resources has pushed up against the needs of irrigated production agriculture. Hydropower is a feasible energy source only in certain regions of the world, and it accounts for only about 2 percent of the world's energy supply. But its interaction with irrigated agriculture—for instance, through competition for water or resource-sharing agreements—can generate large effects, from local to international. In this paper, we introduce the topic of water competition between the energy and agriculture sectors from a global perspective. To show why this perspective should matter to policymakers, we present a case study of cotton production in Central Asia in which we combine high-resolution geographic information system (GIS) data covering crops and river basins with a partial equilibrium agricultural trade model to simulate the international trade effects of different water policy scenarios.

## What Did the Study Find?

We identified regions of the world where agriculture and hydropower energy sectors compete for the same water resources. Much of the world's hydropower and irrigated agriculture overlap in South and East Asia. As an illustrative case study of this competition's effects on world production and trade outcomes, we selected one region—the Syr Darya river basin in Uzbekistan—as the basis for three scenarios in which irrigated agricultural land is reduced by increasing amounts (10, 25, and 50 percent) due to heightened hydropower demands in the neighboring Kyrgyz Republic. According to our model results:

- For Uzbekistan, all three area-diminishing shocks lead to large reductions in cotton production as well as production of its closest economic substitute, wheat.
- In the most extreme area-reduction scenario (50 percent), Uzbek cotton production falls by 17 percent and cotton exports drop by approximately 21 percent relative to baseline projections.
- These impacts are felt only modestly in international markets, as major producers—the United States, Brazil, and Australia—adjust their production and exports slightly upward in response to higher prices resulting from the reduction in Uzbek cotton exports.
- The results of the simulation, which confirm that world cotton prices barely budge in response to the small shock to world supply, nonetheless illustrate how high-resolution GIS data sets and partial equilibrium trade models can be combined to address new questions concerning natural resource management and market behavior.

## How Was the Study Conducted?

This study used the USDA-ERS Country-Commodity Linked System (CCLS), a large-scale dynamic partial equilibrium simulation system consisting of 43 country and regional models. For the analysis, the authors created a country model for Uzbekistan. They confined their analysis to the Syr Darya river basin, using GIS to overlay high-resolution production data onto a map of the basin to accurately capture the area of production subject to the water shock. To simulate the heightened energy demands placed on the Kyrgyz Republic's Toktogul hydropower reservoir, we reduced Uzbekistan's area in cotton by 10, 25, and 50 percent and observed domestic and international outcomes in production, prices, and trade for each level of reduction.

# Introduction

As growing populations demand more electric power and the need for low-emission energy sources intensifies, interest has risen in hydroelectric power (hydropower) as an alternative to carbon-based sources (Weisser, 2007; Raadal et al., 2011). However, hydropower's demand for water resources has come up against the needs of irrigated production agriculture. Hydropower is a feasible energy source only in certain regions of the world, and it accounts for only about 2 percent of the world's energy supply (Moselle et al., 2010). But its interaction with irrigated agriculture, for instance, through competition for water or resource-sharing agreements, can generate large effects, from local to international. In this paper, we introduce the topic of water competition between the energy and agriculture sectors from a global perspective. To show why this perspective should matter to policymakers, we present a case study of cotton production in Central Asia in which we combine high-resolution geographic information system (GIS) data covering crops and river basins with a partial equilibrium agricultural trade model to simulate the international trade effects of different water policy scenarios.

## Hydropower and Agriculture

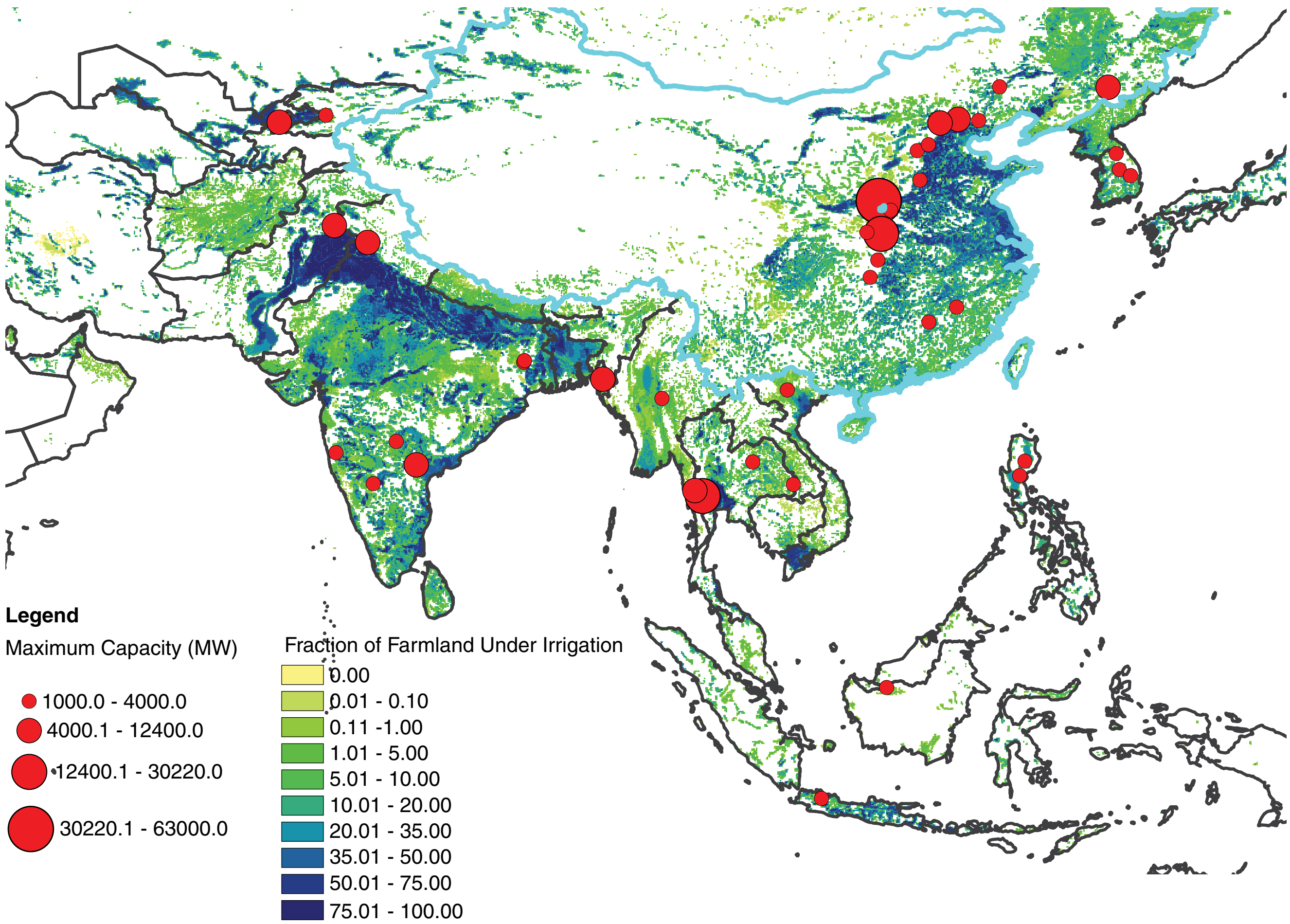
The competition between agriculture and energy sectors for water is not new. A large body of research has focused on the optimal allocation of water between competing uses and under varying constraints (Stamford da Silva and Campello de Souza, 2008; Bielsa and Duarte, 2003; Chatterjee et al., 1998). The problem is twofold. First, power generation typically occurs upstream, where greater capacities can be summoned behind large dams and reservoirs. This may affect water supplies for irrigated agriculture, which takes place in more downstream, riparian settings. Second, the seasonalities of water demand for each sector further complicate matters. For example, peak energy demand in Kyrgyzstan and Tajikistan occurs in the winter months, when water needs to be released from the reservoirs to generate hydropower for heating. In order to have enough energy for the winter months, these upstream countries spend the summer months building up their reservoirs, depriving downstream farmers of water when they most need irrigation. Taking into account the market value of each of the final outputs produced with water, welfare-maximizing solutions can point to water's greatest value use, be it for agriculture, electrical power generation, or perhaps some other use. Often, this value results from some optimal combination of uses. These solutions typically assume one optimizing decisionmaker, but when the rights to the water are spread across multiple owners with differing objectives, globally optimal solutions can be difficult to achieve (Abbink et al., 2010).

Outside the United States, much of the competition between energy and agriculture sectors appears concentrated in South and East Asia (fig. 1). Combining worldwide data on irrigation and hydropower, the map reveals that hydropower generation sits atop many of the continent's most intensively irrigated regions, including the Indus River valley, Central Asia's Amu Darya and Syr Darya valleys, and northeast China's Yangtze River valley. In India, hydropower facilities supply about a quarter of the country's total power needs. But demand there continues to grow, as evidenced by frequent power outages, and policymakers are keen to expand beyond the 23 percent of India's hydropower potential that is currently exploited (World Bank, 2011). About 40 percent of India's cultivated area was under irrigation during the last decade, of which at least 37 percent originated from surface water sources. Over half this area was planted in wheat and rice (Food and Agriculture Organization, 2010b).

Meanwhile, China has the largest hydropower generation capacity in the world, yet this resource accounts for only 15 percent of its total power generation (Chang et al., 2010). As in India, growing demand for electricity in China, particularly in the context of environmental repercussions of coal-burning plants, also portends greater expansion in hydropower capacity in the coming years (Chang et al., 2010). Half of China's cultivated area is irrigated, and of this, about 70 percent comes from surface water sources.[1] As in India, rice and wheat account for the bulk of China's irrigated production, though considerable area is also allocated to maize, vegetables, and soybeans (Food and Agriculture Organization, 2010a).

[1]A more complete description of China's water resource challenges appears in Lohmar et al. (2003).

Figure 1
**South and East Asia irrigation and hydropower**




Note: Circles identify hydropower station locations.
Sources: Siebert et al., 2007; Lehner et al., 2008.

The growing costs of coal and nuclear power—environmental, economic, and social—have raised the profile of alternative sources of clean, sustainable power generation. Hydropower generation offers an option for countries endowed with the right resources. Greenhouse gas emissions from hydropower plants are much lower. There are no radioactive byproducts. Hydropower's chief input replenishes itself via evaporation and precipitation, making the process generally sustainable. And since water can be stored behind dams, power generation can be adjusted in rapid response to fluctuations in demand. On the other hand, hydropower can leave a heavy environmental footprint in its vicinity, disrupting natural water bodies and complex ecosystems. Policymakers thus face the challenge of weighing a complex balance of costs and benefits in considering the use of hydropower.

Competition for water resources spans geographic regions and relates directly to policies concerning the economy, environment, and security. The authors address the specific case of Central Asia and explore how the prevalence of hydropower may affect international trade in cotton. Our purpose is to offer an overview of the tensions between agriculture and hydropower in this region and illustrate the possible impacts of water reduction scenarios on regional and global production and trade outcomes. The analysis relies on relatively unrefined data and rests on strong assumptions, but it reveals that the little-studied intersection of agriculture and energy deserves more attention.

# Central Asia's Water and Energy Conflict

Following the dissolution of the Soviet Union in December 1991, the five Soviet republics of Central Asia suddenly became responsible for decisions that were previously made in Moscow. One outcome of this new arrangement of power was the absence of a region-wide perspective on natural resource management. During the Soviet era, water resources across the republics were managed for the purpose of maximizing cotton production, an objective that suited the Soviet Union's larger economic goals. Specifically, rivers that originated in the glaciers of the Kyrgyz Republic and Tajikistan flowed into the riparian republics of Uzbekistan, Kazakhstan, and Turkmenistan, where they were tapped for irrigation. In exchange, the upstream regions received gas and coal to cover their energy demand during the winter months.

Following independence, however, the separate republics have pursued objectives that serve their specific interests. In the case of Uzbekistan, the region's largest cotton producer, cotton production is an important traditional source of foreign exchange, and with the development of new trade links, Uzbek natural gas, once destined for regional consumption, has become another source of foreign exchange. Meanwhile, the neighboring Kyrgyz Republic plans to increase hydroelectric production to generate energy for domestic use and perhaps even to export to neighboring countries. Kazakhstan also faces new challenges, as exporting petroleum to satisfy next-door China's growing demand offers new economic opportunities. However, water consumption is also surging in China, potentially limiting Kazakhstan's access to riparian resources now shared by the two countries.

Recent work by Abdullaev et al. (2009) focused on the effect of different trade policy scenarios on Uzbekistan's scarce water resources. These authors show that trade liberalization, elimination of government production quotas, and the consequent introduction of international price signals into the Uzbek market would raise prices paid to wheat and cotton farmers and drive expansion in area under cultivation. However, given that Uzbek cotton is more competitive than Uzbek wheat, the balance of planted area would shift toward cotton production, disproportionately raising the demand for water owing to cotton's relative thirstiness.

This study spotlights the effects of competition between Central Asia's agriculture and energy sectors for the region's scarce water. It also presents the trade and production impacts of plausible water scenarios within the Syr Darya river basin. The discussion and simulation results, apart from being of interest to commodity market observers, can also inform policymakers in agriculture, trade, and security of the circumstances that may drive this region's economic and political outcomes in coming years. We begin with some background on Uzbekistan's cotton sector and regional water management and policy issues, followed by discussion of the water policy scenarios and an overview of the economic model used to simulate the scenarios.

## Cotton, Water, and Energy

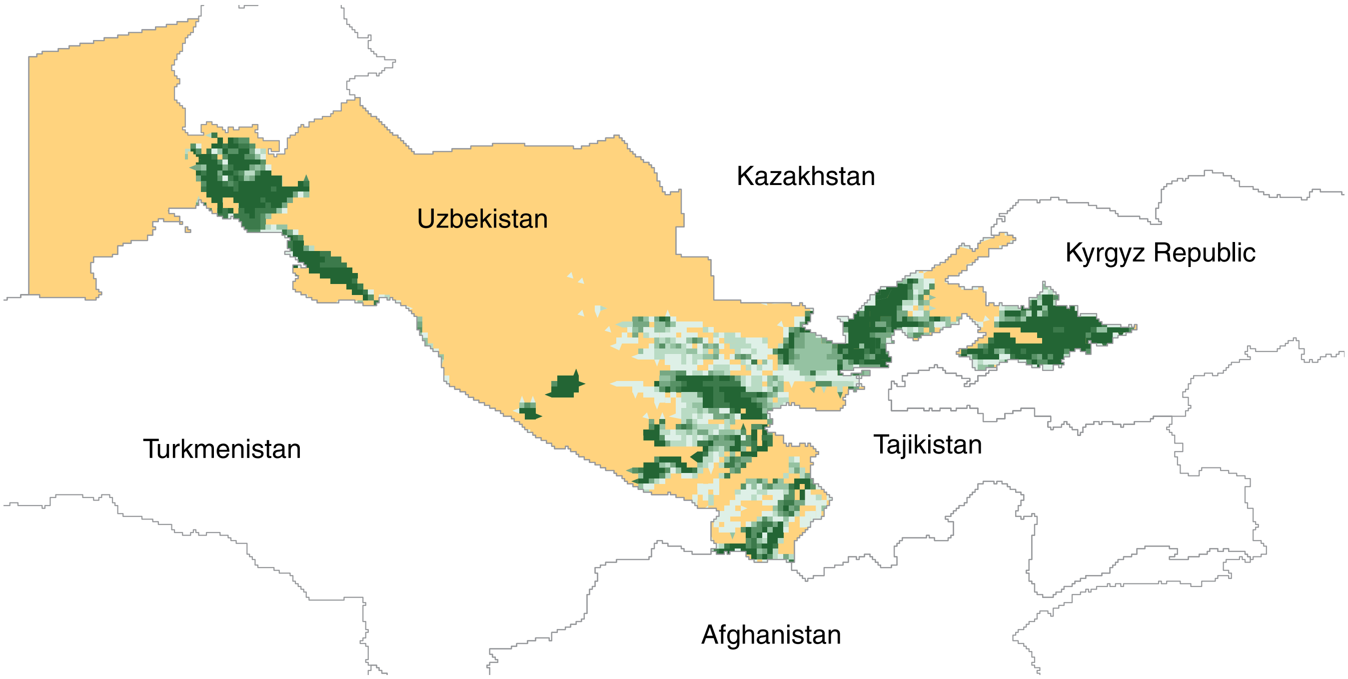
Cotton provides nearly 40 percent of the world's textile fiber for clothing, home textiles, and other products. The physiology of the cotton plant favors irrigated cultivation in arid regions, conditions under which 70 percent of the world's cotton is currently produced. As the Soviet Union industrialized during the 20th century, Uzbekistan and other Central Asian republics developed extensive irrigation networks. Soviet planners pursued fiber self-sufficiency for their expanding textile industry, and, partly as a result, Central Asia's irrigation capacity continued to expand through the 1980s. When Uzbekistan became independent in December 1991, its exports accounted for about 20 percent of world cotton trade and the country was usually the world's second largest exporter, trailing only the United States.

Since then, world fiber demand has continued to expand dramatically. Cotton has lost market share to petroleum-derived chemical fibers, but world cotton consumption still grew 36 percent between 1990 and 2009. Uzbekistan's cotton area, however, trended downward during this time, and yields there have largely stagnated. The country's isolation from world price signals and the limited ability of individual producers in Uzbekistan to freely choose alternatives in production and investment have constrained development of its cotton sector. Uzbekistan remains a major cotton producer, ranking sixth worldwide, but as other major exporters have adopted genetically modified varieties and other yield-enhancing technologies, its role has diminished. In marketing year 2009-10, Uzbekistan planted approximately 1.3 million hectares in cotton, yielding 893,000 metric tons of fiber. More than 70 percent of its output is still exported, representing 10 percent of total traded cotton worldwide (FAS, 2010). Although landlocked, Uzbekistan transships its cotton to markets around the world, with export receipts that totaled nearly US$1 billion in 2007 (UNCTAD, 2010; FAOSTAT, 2010).

Abdullaev et al. (2009) present a detailed description of the policy environment surrounding Uzbek cotton. Among the policies that shape the decisions and outcomes of cotton producers are land redistribution and farm restructuring, food security initiatives focused on switching from cotton to wheat, and, most relevant to this analysis, production quotas. In Uzbekistan, production quotas are partially fulfilled through mandated area plantings, often without regard for a particular area's suitability for cotton. Moreover, the Uzbek Government relied increasingly on rent extraction from agriculture for a large share of its revenues, and it used State-controlled marketing boards to transfer resources out of agriculture (Pomfret, 2007). USDA's Global Agricultural Information Network reports that the Uzbek Government exerts complete control over prices, material inputs, purchasing, and, ultimately, the domestic and international marketing of all cotton via State-owned trading companies (GAIN, 2010). As a result, Uzbek farmers receive about half the price offered on the world market (Abdullaev et al., 2009).

Figure 2 depicts the spatial distribution of Uzbekistan's cotton production, at a resolution of 5-minute grid cells (You et al., 2010). Most production occurs in Uzbekistan's easternmost provinces along the borders of the Kyrgyz Republic and Tajikistan, as well as in its western province of Karakalpakstan, along the border of Turkmenistan. Given the country's arid climate, all cotton in Uzbekistan is

Figure 2
**Grid cell-level cotton production in Uzbekistan**



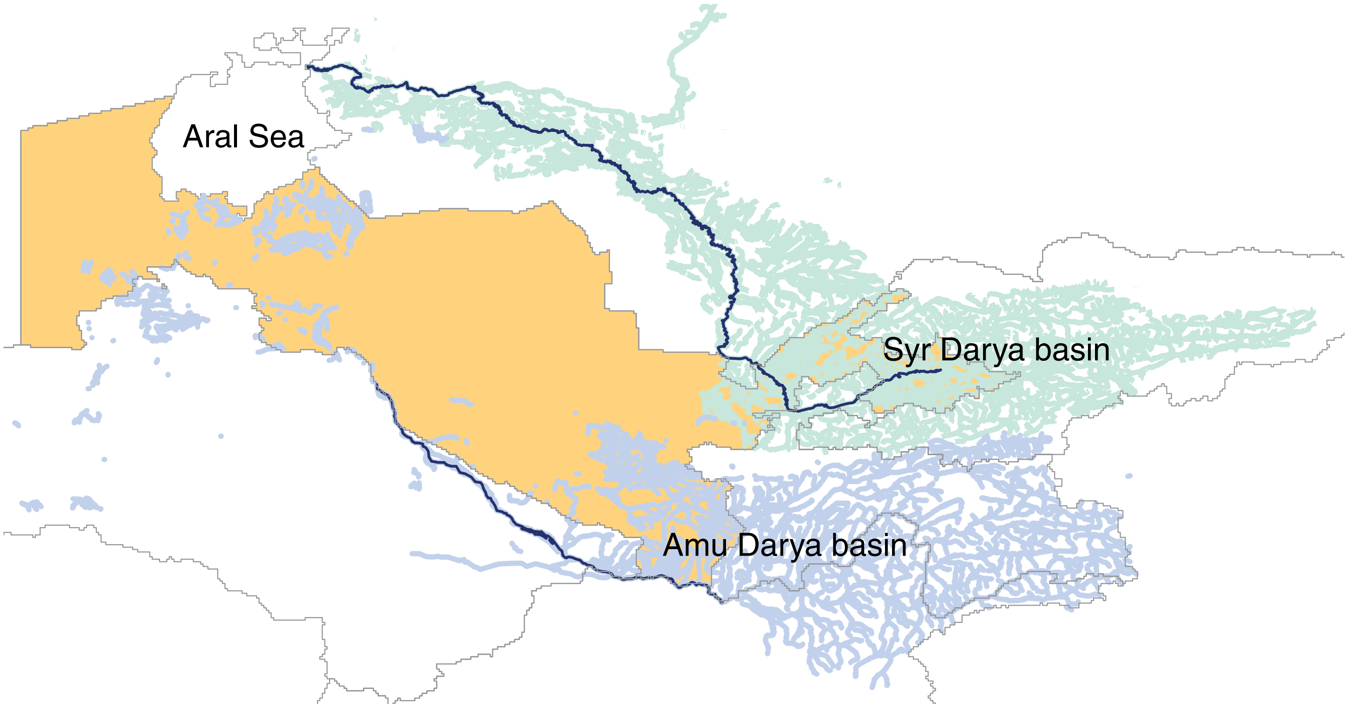

Note: Upper-bound value, represented by the darkest shade of green, is approximately 3,000 metric tons.
Source: You et al., 2010.

cultivated under irrigation. This is supplied from two major river basins, the Amu Darya and Syr Darya, with tributaries that originate in the mountains of Tajikistan and the Kyrgyz Republic. Figure 3 depicts these two river basins and the multiple countries through which they flow. The Syr Darya River, the subject of this report's analysis, originates in the Tien Shan Mountains and flows through the upstream countries of Kyrgyzstan and Tajikistan, through Uzbekistan and Kazakhstan, stretching a total of 2,000 kilometers until it finally flows into the Aral Sea.[2] From figures 2 and 3, it is clear not only that cotton cultivation closely depends on water availability, but also that successful water management demands significant coordination across countries.

We focus on the Syr Darya river basin due to its vulnerability to major swings in management. During the Soviet era, large dams were erected along the Naryn River in the Kyrgyz Republic, designed to ensure a consistent year-to-year supply of water for downstream irrigation purposes, as well as to supplement the region's electricity needs. The largest of these dams formed a reservoir at Toktogul, about 85 kilometers inside the Kyrgyz border. Meanwhile, to meet Kyrgyzstan's power and heating needs, coal, oil, and gas resources were brought in from other republics, namely Uzbekistan and Kazakhstan (World Bank, 2004). After independence in 1991, however, the water-for-energy exchange that served both republics for over 40 years began to deteriorate, accelerated by higher energy prices in the late 1990s and early 2000s. Economic openness permitted Uzbek natural gas to receive a high international price, far above what its eastern neighbor was accustomed to paying. Consequently, in order to generate winter heat for its own population,

[2]The contamination and near-depletion of the Aral Sea during the Soviet era and its aftermath has significantly damaged the ecology of the Aral Sea region, with impacts on both human and wildlife populations (Glantz et al., 1993). The need for rehabilitation has been acknowledged, but damage to the Aral Sea continues due to the intensive cotton monoculture that the region has practiced over the past 50 years. While this study does not address the environmental and economic impacts of water management on the Aral Sea specifically, it is clear that this important region cannot be excluded from any comprehensive treatment of the topic of cotton production in Central Asia.

Figure 3
**Amu Darya and Syr Darya Rivers and basins of Central Asia**




Source: McKinney, 2005.

the Kyrgyz Republic increasingly shifted its water releases from the summer to the winter. This resulted in less water reaching downstream farmers precisely when their crops needed it most. Over the period 1991-2000, the fraction of annual water released during the summer fell from three-fourths to below one-half (World Bank, 2004).

Recently, rolling blackouts and energy price hikes during the winter of 2009-10 culminated in the replacement of President Kurmanbek Bakiyev with a new interim government, highlighting the importance of a stable and affordable electricity supply for the Kyrgyz Republic. Precedents exist for such events to add pressure to violate agreements on water and energy sharing between Uzbekistan, Kazakhstan, and the Kyrgyz Republic (World Bank, 2004).

Eighty percent of Uzbekistan's water originates from its neighbors (Abdullaev et al., 2009). The Toktogul hydropower station, Kyrgyzstan's largest power plant, and four downstream stations along the Naryn River account for nearly 80 percent of the country's electric capacity (The World Bank, 2004). About 36 percent of Uzbekistan's total cotton production occurs within the Syr Darya river basin (figures 2 and 3). The Kyrgyz Republic's decisions regarding energy security could affect one of the world's most important cotton exporters. The immediate problems of water management in this region are intensified by increasingly scarce water resources that stem from a warming climate. For these reasons, this study evaluates a set of water scenarios designed to simulate Uzbek and worldwide production and trade outcomes resulting from a range of management decisions that could be taken by the Kyrgyz Republic.

## Commodity Trade Model

This study uses the USDA-ERS Country-Commodity Linked System (CCLS), a large-scale dynamic partial equilibrium simulation system consisting of 43 country and regional models. Each country and region is modeled to reflect domestic and trade policies and institutional behavior, such as tariffs, subsidies, and tariff rate quotas. Production, consumption, imports, and exports are endogenous and depend on domestic and world prices, which are solved within the modeling system. Macroeconomic assumptions and projections are exogenous, based on USDA's 10-year agricultural projections (USDA, 2010). The system reaches simultaneous equilibrium in prices and quantities for 24 world commodity markets for each of the 10 projected years in the analysis. The 24 commodity markets include detailed coarse grains, food grains, oilseeds, meals, oils, cotton, sugar, and animal products. Primary data sources are USDA's Production, Supply, and Distribution database, USDA's National Agricultural Statistical Service, and the United Nations Food and Agriculture Organization's FAOStat.

The USDA-ERS Uzbekistan model is used for analyzing potential changes in planting area, the impact of planting changes on Uzbek agriculture, and the ultimate effect on international cotton markets and trade. The model treats the Uzbek Government as the planting decisionmaker, inasmuch as the Government determines how much acreage to plant from year to year. Production, consumption, imports, exports, and ending stocks are endogenous and depend on prices. World price signals enter the domestic market through the border price. However, for Uzbekistan, production decisions are heavily influenced by Government intervention. Uzbekistan directly influences the international market and world prices through its cotton exports. All commodities are modeled at the national level except for cotton and wheat, which are disaggregated at the level of the Syr Darya and Amu Darya river basins.

The Uzbekistan model has a cotton sector, six livestock sectors, four grain sectors, and four oilseed sectors. The major commodities include cotton, wheat, and beef. The individual commodities of the Uzbekistan model have five major components: prices and expected revenue equations, production, consumption, ending stocks, and trade equations. As mentioned, cotton and wheat production are modeled at the river-basin level. Each basin is represented by individual area harvested and yield equations. Country-level production for both cotton and wheat is the sum of production in the two basins.

The cotton sector includes cotton, cottonseed, cottonseed oil, and cottonseed meal. Cotton production in both river basins is calculated by equations of the area harvested times the yield. Area harvested and yields are determined by expected returns for cotton and substitute crops, namely wheat. As stated above, 36 percent of total cotton area is located in the Syr Darya river basin at the beginning of the projection period. Expected returns are determined by producer prices times an expected yield.

The price transmission elasticity from the world cotton price to the producer price was estimated to be 0.85.[3] Cotton acreage, a Government decision, is a function of the international reference price, exchange rates, and the quantity of cotton exported. This variable captures the Government incentive to increase foreign exchange holdings.

[3]This estimate was obtained by a double log regression of the Uzbekistan cotton lint border price on the real international price of cotton, based on annual data over the past 16 years.

The CCLS model relies on a variety of own- and cross-price elasticities, as well as substitution elasticities, taken from extensive literature covering cotton production, trade, and consumption (Baffes and Ajwad, 1998; Baffes and Ajwad, 2001; Poonyth et al., 2004; Meyer, 2002; Shepherd, 2006). Additional estimates from the wheat sector are taken from the elasticity database of the Food and Agricultural Policy Research Institute (FAPRI, 2012). Based on a review of this previous research, we set the own-price supply response of cotton's expected revenues to 0.31, the own-price demand elasticity of cotton to -0.20, and the income elasticity to 0.40. The cross-price response of cotton to wheat is assumed to be -0.15. Area harvested, consumption, and trade adjust as the model solves for world prices and reaches a new equilibrium. The cotton exports equation is an identity that closes the model. The cottonseed sector includes production, crushed cottonseed demand, feed demand, ending stocks, and imports and exports. Cottonseed meal and cottonseed oil production depend on cottonseed crushed demand. Cottonseed meal and cottonseed oil are consumed domestically for feed and food, respectively.

Since the chief substitute for cotton is wheat, we also introduce a river-basin-level wheat sector. The wheat sector model includes border, producer, and consumer prices, expected returns, production, food and feed demand, ending stocks, and trade. Domestic prices are determined by the world price, with a price transmission from the world price to the producer price assumed to be 0.50. Expected returns are determined by the producer price times an expected yield. Wheat production in both river basins is calculated from the equations of area harvested times the yield. At the beginning of the projection period, the Syr Darya river basin holds 69 percent of total wheat area in the country. Area harvested is a function of expected returns for wheat and its substitutes, cotton and cash crops. As with cotton, elasticities are taken from a variety of sources in the literature (FAPRI, 2012; Devadoss et al., 1989). The own-price supply response of wheat's expected revenues is set at 0.40. Wheat's cross-price elasticity with respect to cotton's expected return is -0.15. Again, area harvested and consumption adjust as the model solves for world wheat prices and reaches a new equilibrium. Wheat's own-price elasticity of demand is set at -0.23, and its income elasticity is 0.08. Wheat feed demand elasticities include an own-price value of -0.40, and the cross price elasticity of its nearest substitute, barley, is 0.25. Wheat import demand is an identity that closes the model.

We stress that our analysis focuses strictly on global production and trade effects resulting from reductions in area harvested, a variable that plausibly captures the effect of upstream water shocks. Furthermore, we do not address the complex economic and physical interactions and substitutions between electricity demand, water use, and downstream agriculture, nor does our model account for prices of inputs. Such tasks are more suited to a resource economic model that explicitly incorporates the endogeneity of prices, demand, and substitution possibilities. While such features would undoubtedly add greater detail and realism to our results, our primary purpose is to examine the macro-level impacts of water shocks, for which the precise and subtle details provided in a resource economic model offer little advantage. As detailed in the literature review, considerable research has been devoted to examining the economic and physical details of electricity and agriculture water demand in this region.

## Scenario Results

Our area-reduction scenarios are based on a hypothetical, sustained reduction in water released from the Toktogul reservoir during the summer to meet the Kyrgyz Republic's increasingly strict winter energy security demands, beginning in year 2010. Less water is expected to translate into less area under cultivation.[4] To capture the effect of a range of possible reductions, we negatively shock Uzbekistan's area harvested in the Syr Darya basin for cotton and its chief substitute, wheat. Over the last 15 years, Uzbekistan has been struck by drought twice (Glantz, 2005; Cotton Outlook, 2008). Each time, area planted in cotton fell by roughly 10 percent. For the purposes of this analysis, we determined that 10 percent can therefore be treated as the upper end of the shocks typically experienced by Uzbekistan under the current de facto regime of regional water management. Systemic changes in climate or water management were therefore modeled as shocks approximately twice the magnitude of the observed shocks (a 25-percent reduction) and also as an extreme case that once more doubles the 25-percent shock to 50 percent.

[4]Rather than assume a quantity of electricity or water demand upstream, we simply begin with an area-reduction scenario. This abstracts away from the details associated with energy and water prices and the technical conversion factors between water volumes and hydropower generation, permitting our analysis to focus on the production and trade outcomes.

In each scenario, the reduction in area harvested in the Uzbekistan's Syr Darya basin lowers cotton production and, not surprisingly, reduces exports. (See fig. 4 for the projected year-to-year changes to Uzbekistan's area harvested, production, and exports.[5] When we take the 25-percent area reduction scenario as an example, overall Uzbek production in 2010 is predicted to fall by about 9 percent relative to the baseline value, a drop of 97,000 metric tons. This affects exports nearly one-to-one; they fall by nearly 11 percent relative to the baseline, or 91,000 metric tons. The effects 10 years later are only slightly dampened. (See tables 1 through 3 for a summary of level and percentage changes for Uzbekistan's production, imports, exports, and consumption.)

[5]Note that the model's baseline scenario reflects the shock and subsequent recovery from the year 2008 world agriculture crisis, which affected prices, production, and exports across numerous commodities worldwide.

Wheat production in the Syr Darya basin also falls, again due to its dependence on irrigation. Under the 25-percent scenario, wheat production falls 17 percent relative to the baseline value across the projection period. As production falls with the area decrease, imports are needed to meet domestic consumption demand. Wheat imports, under the 25-percent scenario, double relative to the baseline. U.S. and EU exports of wheat respond slightly, with roughly a 1-percent increase above the baseline. As noted, wheat and cotton are substitutes governed by a cross-price elasticity. If the price of cotton falls relative to the price of wheat, some areas can be expected to be shifted into wheat production. Wheat also requires less water per area planted, which is not currently reflected in the model. For this reason, the response of wheat presented in figure 5 is likely to be understated.

In response to the simulated area reduction in Uzbekistan, the international price of cotton is projected to rise. Figure 6 shows that, relative to the baseline scenario, prices are only slightly higher. The largest shock drives prices upward only about 2 percent relative to the baseline. The baseline projection, moreover, shows a gradual secular decline in prices that dominates any effect attributable to Uzbekistan. The increase in cotton prices induces a small decrease, relative to the baseline, in the amount of imports from the top cotton importing countries China, Pakistan, Bangladesh, and Indonesia (tables 1 through 3).

Figure 4
**Syr Darya-specific area-reduction impacts on Uzbek cotton**

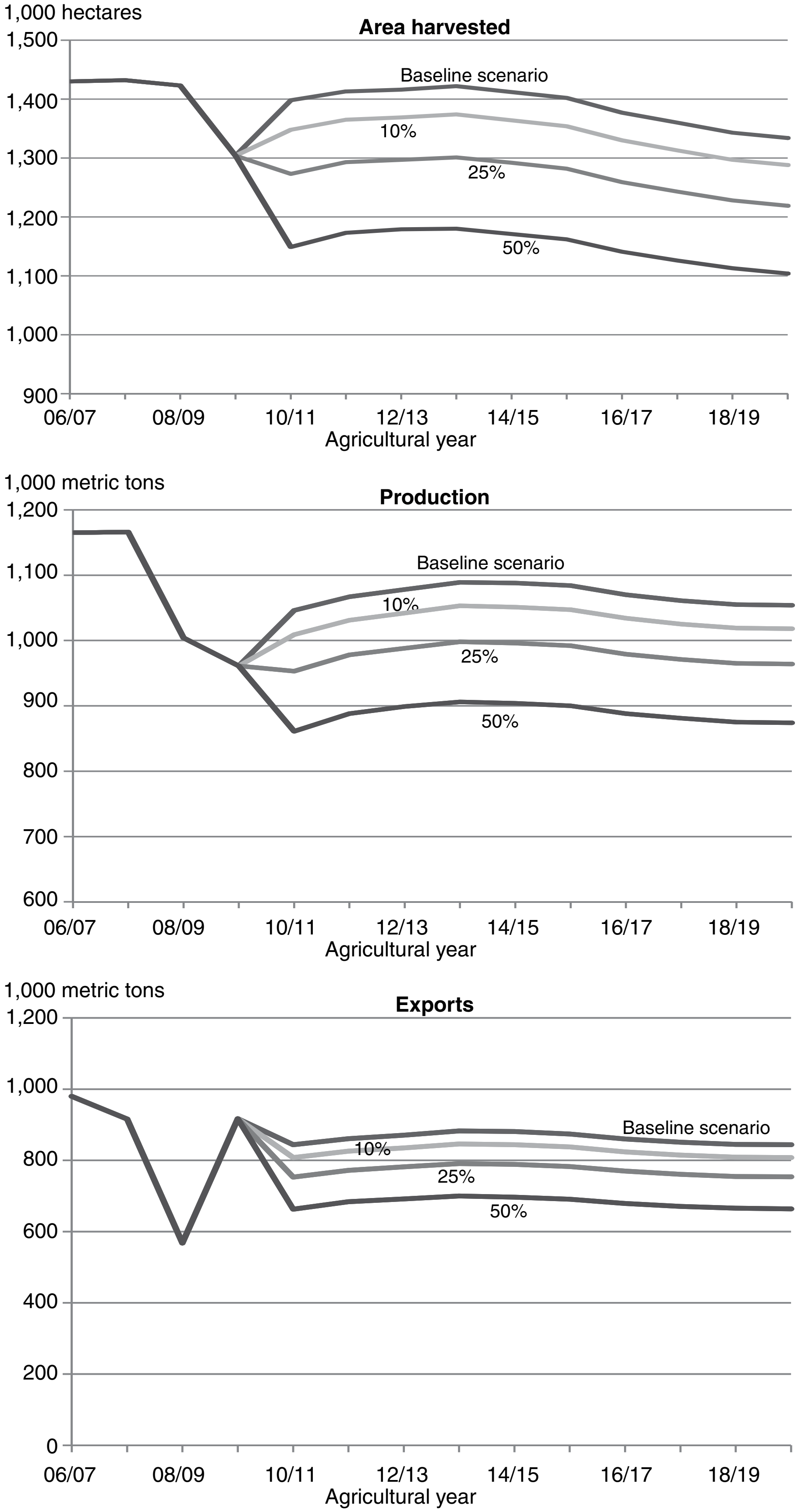


Table 1

**Results from the scenario of a 10-percent reduction in cotton area**

| | | Production | | | Imports | | | Exports | | | Consumption | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2010 | 2015 | 2020 | 2010 | 2015 | 2020 | 2010 | 2015 | 2020 | 2010 | 2015 | 2020 |
| | | | | | | | *1,000 metric tons* | | | | | | |
| | Baseline | 1,046 | 1,084 | 1,054 | 0 | 0 | 0 | 844 | 874 | 844 | 205 | 206 | 208 |
| Uzbekistan | scenario | 1,009 | 1,047 | 1,018 | 0 | 0 | 0 | 808 | 838 | 808 | 205 | 206 | 208 |
| | % change | -3.53 | -3.39 | -3.42 | - | - | - | -4.29 | -4.20 | -4.26 | 0.00 | -0.04 | -0.04 |
| | | | | | | Top exporters | | | | | | | |
| | Baseline | 2,991 | 3,781 | 4,106 | 2 | 2 | 2 | 2,324 | 2,866 | 3,176 | 948 | 900 | 867 |
| USA | scenario | 2,991 | 3,788 | 4,112 | 2 | 2 | 2 | 2,331 | 2,880 | 3,191 | 947 | 893 | 859 |
| | % change | 0.00 | 0.18 | 0.16 | 0.00 | 0.00 | 0.00 | 0.30 | 0.47 | 0.46 | 0.00 | -0.72 | -0.93 |
| | Baseline | 5,434 | 6,430 | 7,254 | 112 | 97 | 85 | 1,427 | 1,536 | 1,639 | 4,158 | 4,997 | 5,725 |
| India | scenario | 5,438 | 6,439 | 7,263 | 111 | 96 | 85 | 1,436 | 1,546 | 1,648 | 4,158 | 4,996 | 5,724 |
| | % change | 0.00 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0.00 | - | - |
| | Baseline | 1,489 | 1,788 | 1,930 | 77 | 69 | 66 | 683 | 895 | 973 | 925 | 949 | 998 |
| Brazil | scenario | 1,489 | 1,790 | 1,932 | 77 | 69 | 66 | 690 | 897 | 975 | 925 | 949 | 998 |
| | % change | 0.00 | 0.11 | 0.1 | 0.00 | 0.00 | 0.00 | 1.09 | 0.28 | 0.24 | 0.00 | -0.05 | -0.04 |
| | Baseline | 476 | 572 | 621 | 0 | 0 | 0 | 451 | 577 | 626 | 9 | 8 | 8 |
| Australia | scenario | 476 | 583 | 621 | 0 | 0 | 0 | 451 | 587 | 626 | 9 | 8 | 8 |
| | % change | -0.02 | 0.04 | 0.03 | - | - | - | 0.03 | 0.04 | 0.03 | 0.00 | 0.00 | 0.00 |
| | | | | | | Top importers | | | | | | | |
| | Baseline | 7,650 | 8,830 | 9,560 | 2,263 | 2,880 | 3,241 | 13 | 11 | 11 | 10,335 | 12,072 | 13,188 |
| China | scenario | 7,650 | 8,832 | 9,561 | 2,259 | 2,878 | 3,239 | 13 | 11 | 12 | 10,333 | 12,071 | 13,188 |
| | % change | 0.00 | 0.02 | 0.02 | -0.15 | -0.09 | -0.06 | 0.31 | 0.39 | 0.36 | 0.00 | -0.01 | 0.00 |
| | Baseline | 10 | 11 | 12 | 965 | 1,200 | 1,419 | 0 | 0 | 0 | 971 | 1,209 | 1,429 |
| Bangladesh | scenario | 10 | 11 | 12 | 964 | 1,199 | 1,419 | 0 | 0 | 0 | 970 | 1,209 | 1,429 |
| | % change | 0.05 | 0.09 | 0.08 | -0.05 | -0.04 | -0.03 | - | - | - | 0.00 | -0.04 | -0.03 |
| | Baseline | 387 | 323 | 268 | 760 | 874 | 967 | 27 | 28 | 29 | 1,119 | 1,168 | 1,206 |
| Turkey | scenario | 387 | 323 | 268 | 760 | 874 | 967 | 27 | 28 | 29 | 1,119 | 1,167 | 1,206 |
| | % change | 0.00 | 0.00 | 0.00 | -0.05 | -0.03 | -0.02 | 0.00 | 0.00 | 0.00 | 0.00 | -0.02 | -0.02 |
| | Baseline | 6 | 6 | 6 | 516 | 520 | 527 | 4 | 4 | 4 | 516 | 522 | 529 |
| Indonesia | scenario | 6 | 6 | 6 | 516 | 520 | 527 | 4 | 4 | 4 | 516 | 522 | 528 |
| | % change | 0.11 | 0.08 | 0.07 | -0.06 | -0.05 | -0.04 | 0.00 | 0.00 | 0.00 | 0.00 | -0.05 | -0.04 |
| | Baseline | 2,116 | 2,525 | 2,634 | 678 | 785 | 923 | 50 | 50 | 50 | 2,685 | 3,224 | 3,469 |
| Pakistan | scenario | 2,117 | 2,526 | 2,635 | 676 | 783 | 921 | 50 | 50 | 50 | 2,684 | 3,223 | 3,468 |
| | % change | 0.03 | 0.04 | 0.03 | -0.29 | -0.23 | -0.17 | 0.00 | 0.00 | 0.00 | 0.00 | -0.03 | -0.02 |

Table 2
**Results from the scenario of a 25-percent reduction in cotton area**

| | | Production | | | Imports | | | Exports | | | Consumption | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2010 | 2015 | 2020 | 2010 | 2015 | 2020 | 2010 | 2015 | 2020 | 2010 | 2015 | 2020 |
| | | *1,000 metric tons* | | | | | | | | | | | |
| | Baseline | 1,046 | 1,084 | 1,054 | 0 | 0 | 0 | 844 | 874 | 844 | 205 | 206 | 208 |
| Uzbekistan | scenario | 953 | 992 | 964 | 0 | 0 | 0 | 753 | 783 | 754 | 205 | 206 | 208 |
| | % change | -8.82 | -8.48 | -8.55 | - | - | - | -10.74 | -10.49 | -10.65 | 0.00 | -0.11 | -0.09 |
| Top exporters | | | | | | | | | | | | | |
| | Baseline | 2,991 | 3,781 | 4,106 | 2 | 2 | 2 | 2,324 | 2,866 | 3,176 | 948 | 900 | 867 |
| USA | scenario | 2,991 | 3,799 | 4,122 | 2 | 2 | 2 | 2,341 | 2,900 | 3,212 | 945 | 884 | 847 |
| | % change | 0.00 | 0.46 | 0.4 | 0.00 | 0.00 | 0.00 | 0.74 | 1.16 | 1.14 | 0.00 | -1.79 | -2.32 |
| | Baseline | 5,434 | 6,430 | 7,254 | 112 | 97 | 85 | 1,427 | 1,536 | 1,639 | 4,158 | 4,997 | 5,725 |
| India | scenario | 5,442 | 6,454 | 7,277 | 110 | 95 | 84 | 1,449 | 1,561 | 1,663 | 4,157 | 4,995 | 5,722 |
| | % change | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Baseline | 1,489 | 1,788 | 1,930 | 77 | 69 | 66 | 683 | 895 | 973 | 925 | 949 | 998 |
| Brazil | scenario | 1,489 | 1,793 | 1,935 | 77 | 69 | 66 | 701 | 901 | 979 | 924 | 948 | 997 |
| | % change | 0.00 | 0.27 | 0.24 | 0.00 | 0.00 | 0.00 | 2.72 | 0.70 | 0.61 | 0.00 | -0.11 | -0.1 |
| | Baseline | 476 | 572 | 621 | 0 | 0 | 0 | 451 | 577 | 626 | 9 | 8 | 8 |
| Australia | scenario | 476 | 584 | 621 | 0 | 0 | 0 | 451 | 587 | 627 | 9 | 8 | 8 |
| | % change | -0.05 | 0.10 | 0.07 | - | - | - | 0.08 | 0.10 | 0.07 | 0.00 | 0.00 | 0.00 |
| Top importers | | | | | | | | | | | | | |
| | Baseline | 7,650 | 8,830 | 9,560 | 2,263 | 2,880 | 3,241 | 13 | 11 | 11 | 10,335 | 12,072 | 13,188 |
| China | scenario | 7,650 | 8,835 | 9,564 | 2,254 | 2,874 | 3,236 | 13 | 11 | 12 | 10,330 | 12,070 | 13,187 |
| | % change | 0.01 | 0.05 | 0.05 | -0.37 | -0.22 | -0.16 | 0.79 | 0.98 | 0.91 | 0.00 | -0.01 | -0.01 |
| | Baseline | 10 | 11 | 12 | 965 | 1,200 | 1,419 | 0 | 0 | 0 | 971 | 1,209 | 1,429 |
| Bangladesh | scenario | 10 | 11 | 12 | 964 | 1,198 | 1,418 | 0 | 0 | 0 | 969 | 1,208 | 1,428 |
| | % change | 0.14 | 0.23 | 0.19 | -0.13 | -0.09 | -0.08 | - | - | - | 0.00 | -0.09 | -0.08 |
| | Baseline | 387 | 323 | 268 | 760 | 874 | 967 | 27 | 28 | 29 | 1,119 | 1,168 | 1,206 |
| Turkey | scenario | 387 | 323 | 268 | 759 | 873 | 966 | 27 | 28 | 29 | 1,119 | 1,167 | 1,205 |
| | % change | 0.00 | 0.00 | -0.01 | -0.13 | -0.07 | -0.05 | 0.00 | 0.00 | 0.00 | 0.00 | -0.05 | -0.04 |
| | Baseline | 6 | 6 | 6 | 516 | 520 | 527 | 4 | 4 | 4 | 516 | 522 | 529 |
| Indonesia | scenario | 6 | 6 | 6 | 515 | 519 | 526 | 4 | 4 | 4 | 515 | 521 | 528 |
| | % change | 0.27 | 0.20 | 0.17 | -0.16 | -0.13 | -0.11 | 0.00 | 0.00 | 0.00 | 0.00 | -0.12 | -0.11 |
| | Baseline | 2,116 | 2,525 | 2,634 | 678 | 785 | 923 | 50 | 50 | 50 | 2,685 | 3,224 | 3,469 |
| Pakistan | scenario | 2,118 | 2,527 | 2,636 | 673 | 780 | 919 | 50 | 50 | 50 | 2,682 | 3,222 | 3,467 |
| | % change | 0.07 | 0.1 | 0.07 | -0.74 | -0.57 | -0.44 | 0.00 | 0.00 | 0.00 | 0.00 | -0.06 | -0.06 |

Table 3

**Results from the scenario of a 50-percent reduction in cotton area**

| | | Production | | | Imports | | | Exports | | | Consumption | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2010 | 2015 | 2020 | 2010 | 2015 | 2020 | 2010 | 2015 | 2020 | 2010 | 2015 | 2020 |
| | | *1,000 metric tons* | | | | | | | | | | | |
| | Baseline | 1,046 | 1,084 | 1,054 | 0 | 0 | 0 | 844 | 874 | 844 | 205 | 206 | 208 |
| Uzbekistan | scenario | 861 | 900 | 874 | 0 | 0 | 0 | 663 | 691 | 664 | 204 | 206 | 208 |
| | % change | -17.66 | -16.96 | -17.08 | - | - | - | -21.49 | -20.98 | -21.29 | 0.00 | -0.22 | -0.19 |
| | | Top exporters | | | | | | | | | | | |
| | Baseline | 2,991 | 3,781 | 4,106 | 2 | 2 | 2 | 2,324 | 2,866 | 3,176 | 948 | 900 | 867 |
| USA | scenario | 2,991 | 3,816 | 4,138 | 2 | 2 | 2 | 2,358 | 2,933 | 3,248 | 941 | 868 | 827 |
| | % change | 0.00 | 0.92 | 0.79 | 0.00 | 0.00 | 0.00 | 1.48 | 2.32 | 2.27 | -1.00 | -3.58 | -4.63 |
| | Baseline | 5,434 | 6,430 | 7,254 | 112 | 97 | 85 | 1,427 | 1,536 | 1,639 | 4,158 | 4,997 | 5,725 |
| India | scenario | 5,451 | 6,479 | 7,300 | 109 | 94 | 83 | 1,470 | 1,587 | 1,687 | 4,155 | 4,993 | 5,720 |
| | % change | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Baseline | 1,489 | 1,788 | 1,930 | 77 | 69 | 66 | 683 | 895 | 973 | 925 | 949 | 998 |
| Brazil | scenario | 1,489 | 1,798 | 1,939 | 77 | 69 | 66 | 720 | 907 | 985 | 923 | 947 | 996 |
| | % change | 0.00 | 0.55 | 0.48 | 0.00 | 0.00 | 0.00 | 5.44 | 1.4 | 1.22 | 0.00 | -0.23 | -0.2 |
| | Baseline | 476 | 572 | 621 | 0 | 0 | 0 | 451 | 577 | 626 | 9 | 8 | 8 |
| Australia | scenario | 476 | 584 | 621 | 0 | 0 | 0 | 451 | 588 | 627 | 9 | 8 | 8 |
| | % change | -0.11 | 0.20 | 0.14 | - | - | - | 0.17 | 0.19 | 0.13 | 0.00 | 0.00 | 0.00 |
| | | Top importers | | | | | | | | | | | |
| | Baseline | 7,650 | 8,830 | 9,560 | 2,263 | 2,880 | 3,241 | 13 | 11 | 11 | 10,335 | 12,072 | 13,188 |
| China | scenario | 7,651 | 8,839 | 9,568 | 2,246 | 2,867 | 3,230 | 13 | 11 | 12 | 10,325 | 12,068 | 13,186 |
| | % change | 0.01 | 0.10 | 0.09 | -0.74 | -0.44 | -0.32 | 1.58 | 1.95 | 1.81 | 0.00 | -0.03 | -0.02 |
| | Baseline | 10 | 11 | 12 | 965 | 1,200 | 1,419 | 0 | 0 | 0 | 971 | 1,209 | 1,429 |
| Bangladesh | scenario | 10 | 11 | 12 | 962 | 1,197 | 1,417 | 0 | 0 | 0 | 968 | 1,207 | 1,427 |
| | % change | 0.27 | 0.46 | 0.38 | -0.27 | -0.19 | -0.16 | - | - | - | 0.00 | -0.18 | -0.16 |
| | Baseline | 387 | 323 | 268 | 760 | 874 | 967 | 27 | 28 | 29 | 1,119 | 1,168 | 1,206 |
| Turkey | scenario | 387 | 323 | 268 | 758 | 873 | 966 | 27 | 28 | 29 | 1,118 | 1,167 | 1,205 |
| | % change | 0.00 | -0.01 | -0.02 | -0.26 | -0.13 | -0.10 | 0.00 | 0.00 | 0.00 | 0.00 | -0.10 | -0.09 |
| | Baseline | 6 | 6 | 6 | 516 | 520 | 527 | 4 | 4 | 4 | 516 | 522 | 529 |
| Indonesia | scenario | 7 | 6 | 6 | 514 | 519 | 526 | 4 | 4 | 4 | 515 | 521 | 527 |
| | % change | 0.54 | 0.40 | 0.34 | -0.33 | -0.25 | -0.22 | 0.00 | 0.00 | 0.00 | 0.00 | -0.24 | -0.22 |
| | Baseline | 2,116 | 2,525 | 2,634 | 678 | 785 | 923 | 50 | 50 | 50 | 2,685 | 3,224 | 3,469 |
| Pakistan | scenario | 2,119 | 2,529 | 2,638 | 668 | 776 | 915 | 50 | 50 | 50 | 2,679 | 3,220 | 3,465 |
| | % change | 0.14 | 0.19 | 0.15 | -1.48 | -1.15 | -0.87 | 0.00 | 0.00 | 0.00 | 0.00 | -0.13 | -0.12 |

Figure 5

**Syr Darya-specific area-reduction impacts on Uzbek wheat production**

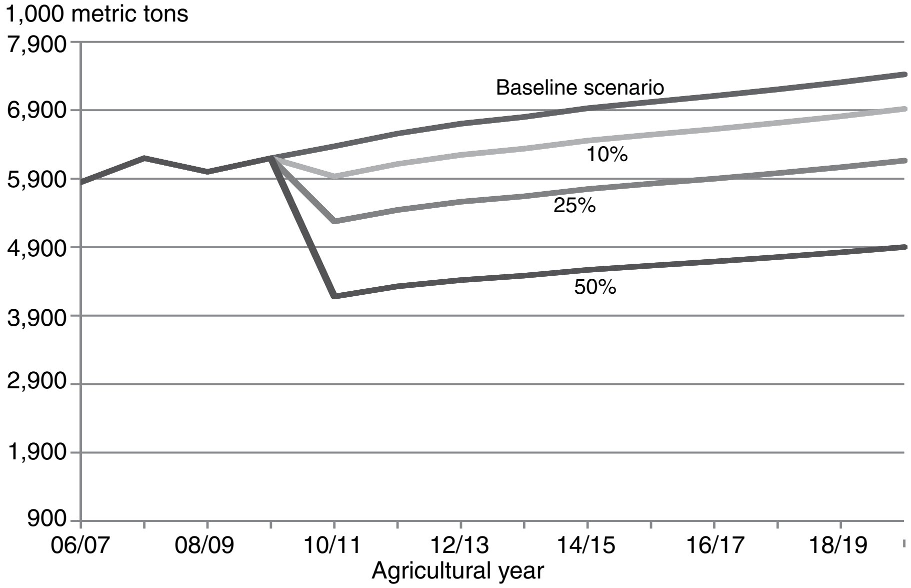
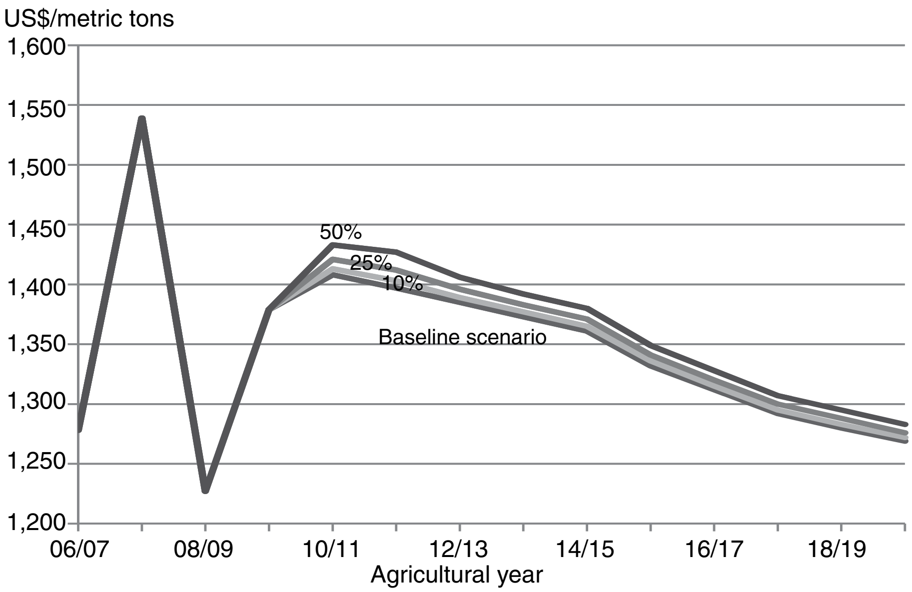



Figure 6

**Syr Darya-specific area-reduction impacts on world cotton prices**

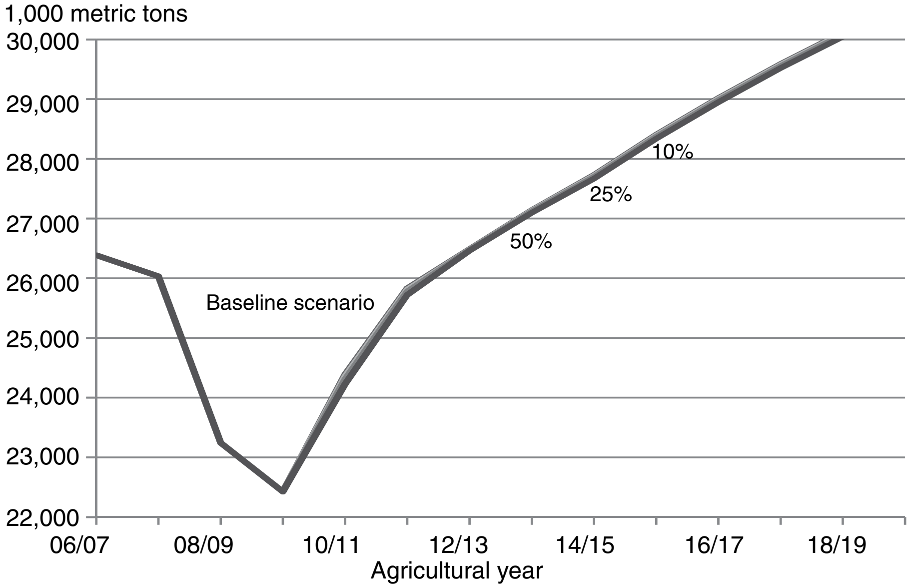



Meanwhile, production in other countries grows to meet the demand historically satisfied by Uzbekistan. As illustrated in figure 7, no significant difference from the baseline scenario can be detected across the different scenarios, as evidenced by the overlapping lines, and any negative effect is more than swamped by the overall rise in worldwide cotton production projected by the baseline. In short, at the world level, the effects appear small. At the country level, as well, the responses are minimal, with major exporters India and the United States registering negligible percentage changes in production.

While world cotton markets could easily absorb the shocks to Uzbekistan's cotton output, the impact for Uzbekistan's economy would be much more

Figure 7

**Syr Darya-specific area-reduction impacts on world cotton production**




significant. With only limited price gains, export revenue from cotton would fall by 4 to 20 percent across the three scenarios. Hundreds of millions of dollars in hard currency earnings would be forgone. In addition to export earnings, cotton production accounts for a significant share of the labor opportunities for Uzbekistan's largely rural population.

## Additional Considerations

The model simulations of cotton area reductions lay a foundation for capturing the impact of hypothetical water scenarios on Uzbekistan's most important agricultural commodity. Refinements to the model can add realism to the predictions. In terms of modeling trade, the effects of Uzbekistan's cotton supply reductions are likely to be felt unevenly across the world market. Currently, the model's one-world price assumption that drives the results ignores the reality that Uzbekistan exports its cotton to a handful of countries. Imposing Armington assumptions—which assume that internationally traded products are differentiated by country of origin and govern the elasticity of substitution between countries—may generate more realistic country-specific results.

Furthermore, the model does not explicitly address the question of energy prices. Under their current, though shaky, arrangement, Uzbekistan and the Kyrgyz Republic exchange water for natural gas at predetermined prices and quantities. But the agreed-upon quantities are periodically ignored, particularly when international prices spike upward or when the winter cold is unpredictably extreme. In either instance, endogenizing the demand for water to world energy prices can add an extra element of realism to the model's predictions.

Additional extensions can include policy levers over the Amu Darya river basin, which falls primarily inside Tajikistan. Unlike the Kyrgyz Republic, Tajikistan's hydropower resources are relatively underdeveloped, and the country has struggled to find investors in its electricity sector. The World Bank has initiated some financing toward this objective, and at least in the medium-term, additional constraints on Uzbekistan's (as well as Turkmenistan's) cotton production capacity are likely to appear.

## Implications From This Study

This study examines the relatively underexplored issue of competition between energy and agriculture for scarce water resources. To illustrate the macro-level tradeoffs between these two sectors, the analysis offers a first attempt at modeling a small portion of the global cotton sector. The scenarios describing the Uzbek-Kyrgyz water conflict are intended to serve as a point of departure for policymakers interested in weighing the response of the two countries to reduced access to water in the near term. The effects of reducing summer water releases from the Toktogul reservoir benefits the Kyrgyz Republic, but downstream, the shock to Uzbekistan's cotton production capacity could be large. Given that one of Uzbekistan's main sources of foreign currency is its cotton sector, such shocks can put vital imports even further out of reach of a population that earns about US$2,400 per capita. Given that Central Asia holds as much as 20 percent of the world's petroleum and natural gas reserves, the area is a crucial future source for satisfying the growing energy needs of China and India. Kazakhstan's continued willingness to expand its role as gateway and source for Central Asian energy shipments to China could be at risk if the two countries' conflicting claims to shared rivers appear insoluble.

Investments in irrigation infrastructure and efficiency, yield enhancements, domestic water-pricing schemes, and international trade agreements could mitigate for Uzbekistan the effects of water scarcity driven by its neighbors' decisions. Indeed, research has shown where improvements in management can enable both Uzbekistan and Kyrgyzstan to satisfy their objectives (Cain et al., 2003).

Similar situations can be postulated in other river basins where both hydropower generation and irrigation are found. As discussed earlier, India and China hold many of these conflicted basins, and in light of each country's growing economy and population, local events can cause dramatic outcomes in production and trade worldwide. An understanding of the equilibrating response of producers and consumers is critical to developing policies that account for the needs of irrigation agriculture. The analysis offers a glimpse into the challenges for international cooperation in the face of growing food and energy demands, as countries with shared sources of water operate under increasing constraints.

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